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A COST EFFECTIVENESS ANALYSIS OF THE NAVAL MODULAR AUTOMATED CO--ETC(U)

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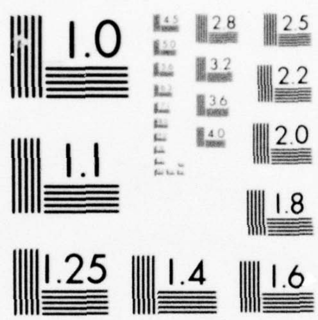

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A COST EFFECTIVENESS ANALYSIS OF THE NAVAL MODULAR AUTOMATED COMMUNICATIONS SYSTEM (NAVMACS)

by:
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This report presents an analysis of the Navy's Afloat Message Communications System, as it will be affected by the Naval Modular Automated Communications System (NAVMACS) Program. Our objective in this analysis has been to assess the impact that alternative decisions concerning the NAVMACS program and its implementation will have on communications costs and effectiveness.

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CHAPTER I

INTRODUCTION AND SUMMARY

This report presents an analysis of the Navy's Afloat Message Communications System, as it will be affected by the Naval Modular Automated Communications System (NAVMACS) program. Our objective in this analysis was to assess the impact that alternative decisions concerning the NAVMACS program and its implementation will have on communications costs and effectiveness.

Based on our analyses summarized below and presented in detail in the following chapters, we conclude that:

1. The V2(A+) and V3(B) NAVMACS configurations appear adequate, or more than adequate, to handle projected Navy communications, including communications during a crisis.

2. The V4 and V5 configurations may not provide significant additional improvements in delay. Alternative approaches, such as stand-alone keyboard entry devices, could provide cost-effective on-line message composition capability aboard ship.

3. Automation using any NAVMACS configuration may not reduce the overall writer-reader delays very much. The real bottleneck in the Navy's message processing system does not lie in the communications link, but in the afloat and ashore communications stations which process hard copies of messages.

4. The V4 and V5 configurations have a high additional cost. (Approximately $70 million present value.)

5. Providing NAVMACS capability only to larger ships is significantly less costly than full automation alternatives.

6. If full automation is deemed desirable for other reasons, the V1 configuration appears to be a cost-effective solution for smaller ships. Further, delaying the introduction of NAVMACS capability on smaller ships until the V1 is available results in significantly lower costs than other full automation alternatives.

This chapter presents an introduction to our report. In Chapter II, a brief description of the NAVMACS program and its relation with other parts of the Navy's communication network is provided. Traffic loads that the NAVMACS may be expected to handle are estimated and analyzed in Chapters III and IV. An analysis of system effectiveness is presented in Chapter V. Chapters VI and VII contain the cost analysis for the NAVMACS program.

A. Program History

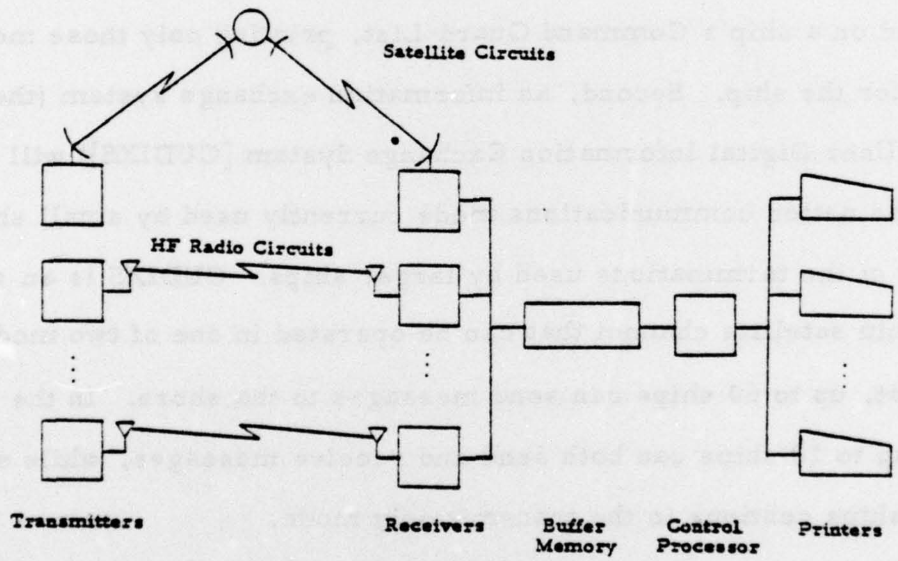
Prior to the 1970's, Navy ship/shore/ship message communications consisted of HF radio circuits operated at teletype speed (75 baud). [1/] Broadcast channels carried messages intended for a number of ships: all messages on the broadcast were printed by each ship desiring to receive some of the messages. Full period terminations provided larger ships with two-way message capability, while smaller ships used a netted ship/shore circuit to send messages. Transmissions were limited to the speeds of the teletypes and their human operators. Moreover, fading and distortion on HF radio sometimes required numerous retransmissions.

Introduction of the GAPFILLER/FLEETSATCOM satellites provided UHF channels which can, in principle, be operated at higher communications rates than teletypes. The Naval Communications Processing and Routing System (NAVCOMPARS) now provides automated capabilities ashore. The NAVMACS program is intended to install an automated terminal aboard the afloat nodes in the communications network. In such an automated system, the manual control of each

1/ A baud is the number of times per second a communications channel changes its state.

circuit would be replaced by computer control. In addition, the computer has a memory which holds messages as they are received, and is able to screen messages based on their addresses. These features permit operation of the satellite channel at speeds temporarily in excess of printer speeds. Figure I-1 illustrates how such a terminal is integrated into the other components of the system.

Figure I-1
Role of Message Processing Automation Afloat



Originally, NAVMACS was to provide six configurations, each built upon common hardware and software components. The original designations for these systems, along with their originally planned

capabilities are shown in Table I-1. Over the past several years, as the implementation of the NAVMACS program has been continually delayed, the configurations and their designations have changed. The current designation is AN/SYQ-7(V1) through (V5). Table I-2 summarizes the main features of the current configurations. Chapter II of this report discusses these data in more detail.

When a NAVMACS configuration is installed aboard ship, there will be several important changes in the way the Navy communicates. First, the broadcast will be transmitted over a 2,400 baud satellite link. NAVMACS will automatically screen the broadcast for messages designated on a ship's Command Guard List, printing only those messages intended for the ship. Second, an information exchange system (the Common User Digital Information Exchange System [CUDIXS]) will replace the netted communications mode currently used by small ships and many of the terminations used by larger ships. CUDIXS is an automated, round-robin satellite channel that can be operated in one of two modes. In the first, up to 60 ships can send messages to the shore. In the second, up to 10 ships can both send and receive messages, while up to 50 more ships continue in the transmit only mode.

Third, NAVMACS V3(B), and the more sophisticated V4 and V5 versions, provide Keyboard Video Display Terminals (KVDT's) which allow a certain amount of on-line message composition and dispatch. The KVDT's thus substitute for the existing TTY/torn-tape method of preparing messages for transmission.

Table I-1

Originally Planned Capabilities of the NAVMACS

Level		
A	Receive only. Broadcast screening.	Teletype printer, paper tape.
A+	Capabilities of A plus transmission capability.	Medium speed line printer, paper tape.
B	Capabilities of A+ plus coordination of up to four terminations, storage and retrieval, message composition and editing.	Same, plus keyboard displays, mag tape.
C	Capabilities of B plus data traffic, remote data terminals, increased storage and processing capability.	Same, plus remote data terminals, and disk drive.
D	Capabilities of C with remote narrative terminals instead of remote data terminals.	Same, except remote narrative terminals.
E	Capabilities of both C and D.	Same as C and D.

Table I-2

Current Capabilities of NAVMACS Configurations

Current System Designation	System Name*	Unit Cost (Thousands of Dollars)	Channels Processed			Remote or On Line Terminals
			Broadcast	CUDIXS	Terminations	
AN/SYQ-7 (V1)	Low Cost Suite	100	4	1**	Torn tape	0
AN/SYQ-7 (V2)	NAVMACS A+	174	4	1	Torn tape	0
AN/SYQ-7 (V3)	NAVMACS B	300	4	1	Torn tape+	2-3
AN/SYQ-7 (V4)	Logistics System (NAVMACS C)	350	10++	1	10++	3-4
AN/SYQ-7 (V5)	Flagship System (NAVMACS D/E)	898	16++	1	16++	4-16

* Superceeded name in parentheses, where applicable.

** Transmit only.

\+ Up to 4 full period terminations may be substituted for broadcast channels.

++ Maximum value. Channels may be split between terminations and broadcasts as required.

B. Framework for Analysis of NAVMACS

In order to see what the effectiveness and cost of the NAVMACS program will be, it is useful to view the Navy's message processing system as a sequence of activities, each of which may cause some delay to a message. Thus, for example, a shore/ship message begins its transit through the Navy's communications system at a shoreside communications center where headers are added and the entire message reproduced in a machine-readable form. A succession of automated and manual communications links (AUTODIN, NAVCOMPARS, HF radio or satellite, and NAVMACS) then process the message in turn. Finally, logging, journaling, duplication, and delivery take place aboard ship.

In a system such as this, delays occur when one or more of these activities has insufficient capacity for the traffic it is required to process. Queues then build up at the transmitting end of the link or links. Without NAVMACS, the speed of message flow is constrained mainly by the limitation of 75 baud of much of the current equipment. In addition, the amount of shipboard manpower required to process messages may be considerable.

NAVMACS, because it permits higher speeds to be used on communications channels, potentially reduces the delay experienced by a message. However, the extent of the NAVMACS program's impact depends on several factors. First, we need to know the capacity in the various NAVMACS configurations in relation to the traffic volumes they will be called on to process. This enables us to assess the potential size of the program's impact. Naturally, the system

should have enough capacity to process the peak loads that occur under crisis conditions. However, once acceptable delays are achieved, the value of still more capacity may be questioned.

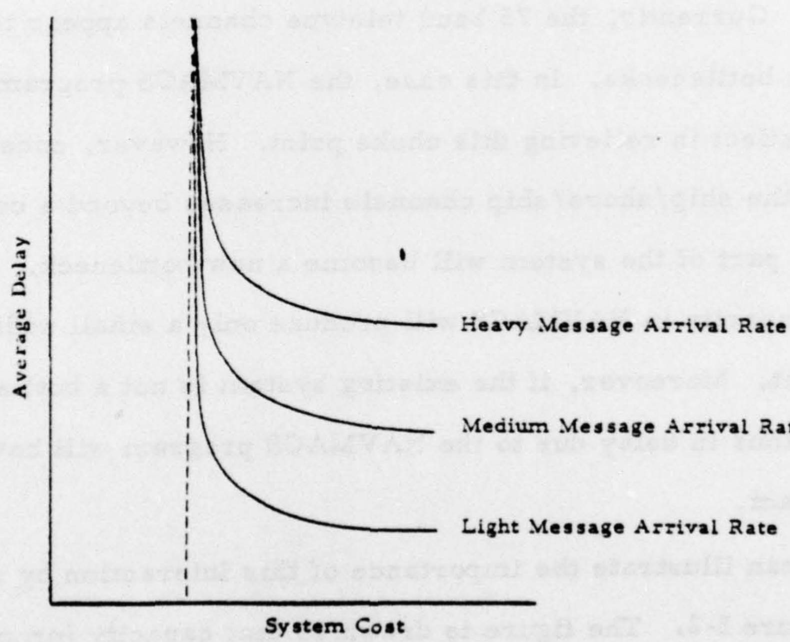
A second set of factors concerns the interaction of a NAVMACS system with the rest of the Navy's message processing system. This interaction is important because apparently large reductions in delays due to NAVMACS may not be realized if the effect of automation is to overload (or further overload) some other part of the system. This is because in a system like the Navy's a few processing steps often constitute bottlenecks which are responsible for most of the delay experienced by a message. Currently, the 75 baud teletype channels appear to constitute one of those bottlenecks. In this case, the NAVMACS program will have some effect in relieving this choke point. However, once the capacity of the ship/shore/ship channels increases beyond a certain point, some other part of the system will become a new bottleneck. Thereafter, additional capacity in NAVMACS will produce only a small additional improvement. Moreover, if the existing system is not a bottleneck, even reductions in delay due to the NAVMACS program will have little overall impact.

We can illustrate the importance of this interaction by a diagram such as Figure I-2. The figure is drawn so that capacity (proportial to cost) is changed at one node (the bottleneck node) only. As can be seen from the figure, there is a minimum capacity (cost) that must be available if any load is to be carried. This minimum level is given by the vertical dashed line. Also, there is a minimum delay associated with any particular

message arrival rate, whatever the capacity of the node. This is because eliminating the delay at any particular node, even with an infinite expenditure on capacity, leaves the rest of the network unchanged. Thus a potential bottleneck becomes a new bottleneck.

Figure I-2

Relationship Between System Cost and Response Time, When Capacity is Changed at One Node Only



C. Analysis of Navy Message Traffic

In order to address the question of NAVMACS' impact on overall communications effectiveness, we performed an analysis of data provided by NAVTELCOM on Navy ship/shore/ship message

traffic. The analysis had two objectives: (1) to estimate the volumes of messages and characters processed by ships during routine operations, and (2) to identify classes of ships with similar traffic volumes.

As a result of our analysis, we determined that the ninety-odd classes of ship in the Navy could be grouped into eleven "aggregate" ship classes. Table I-3 shows these classes, as well as some of our estimates of the number of messages sent per day for each aggregate class. Chapter III presents the results of our analysis in detail. Indeed, because we feel that the work contained therein has some value in its own right, we have presented more information in Chapter III than was actually used in our analysis.

In Chapter IV, we use the data developed in Chapter III to estimate message and character traffic under routine and crises conditions for the 1980's. These estimates are developed in several stages. First, we present a model of the distribution of daily message volumes, and use it to estimate average, 30-day peak, and 365-day peak message volumes. Second, using data provided by NAVTELCOM on the Frequent Wind and Mayaguez operations, we estimate the additional load imposed by crisis conditions. Third, we increase the estimates to take into account the growth in traffic between 1976 (the year for which we have data), and the 1980's, when NAVMACS will be installed throughout the fleet.

One of the results of our analysis in Chapter III, was the finding that command capability was a primary source of large message volumes.

Table I-3

Estimated Number of Daily Messages

(Combined Send and Receive)

	Average	Standard Deviation	Coefficient of Variation	90th Percentile	Number of Observations
Combatants					
CV, CVN	386	278	.72	814	133
Larger CG, CGN	491	332	.68	865	39
Smaller CG, CGN	114	120	1.05	265	54
DD, DDG	55.1-	55.9	1.01	133	94
FF, FFG	41.5	30.5	.73	88	79
Amphibious Warfare Ships					
LCC, LHA, LPD, LPH	179	147	.82	405	143
Other (LKA, LSD, LST, etc.)	47.5	40.5	.85	91	39
Auxiliaries					
AD	228	134	.59	500	30
AFS	118	69.7	.59	199	21
AS	140	113	.81	273	23
Other (AE, AO, AOE, etc.)	82.2	130	1.58	178	59

CV's, the larger CG's, LCC's, LHA's, LPH's, LPD's, AD's and AS's, all had a substantially higher traffic volume than the other ships in the Navy. In predicting traffic growth, we therefore looked for command or other functions which were forcing this growth. Based on limited conversations with Navy personnel, we concluded that command functions might result in an increase of 50 percent in traffic for the ship classes listed above. For other classes, we assumed smaller increases. The final results of our projections are shown in Table I-4. As can be seen from the table, routine message volumes increase by slightly more than 30 percent, and crisis message volumes are 4-5 times the average under routine conditions. Because message lengths increase during a crisis, the character loads, which more accurately depict the load placed on an automated system, increase more than seven-fold. Compared with our 1976 baseline, predicted message traffic during crisis conditions in the 1980's is 5.7 times larger in terms of messages, and 9.0 times larger in terms of characters.

One other point to be noted about Chapters III and IV is our analysis of broadcast message lengths and volumes. These are important because NAVMACS must perform almost as much on a broadcast message that is not addressed to it as on a message that is addressed to it. Thus, extra broadcast messages constitute an important part of NAVMACS processing load. Chapter III contains an analysis of existing broadcast traffic. In Chapter IV, we make estimates of the volume on the 2,400 baud broadcast channels to be used with NAVMACS under routine and

crisis conditions. While the CUDIXS channel is too complex for detailed analysis in this report, we also present some rough estimates of CUDIXS channel loads.

Table I-4

Predicted Daily Message Loads for 1980's

Ship Class	Routine Conditions	Crisis Conditions
Combatants		
Carriers (CVA, CV, CVN, etc.)	600	2600
Larger Cruisers (CG & CGN)	750	3100
Smaller Cruisers(CG & CGN)	120	700
Destroyers (DD & DDG)	75	320
Frigates (FF & FFG)	60	200
Amphibious Warfare Ships		
LCC, LHA, LPH & LPD	270	1300
Other (LKA, LSD, LST, etc.)	60	250
Auxiliaries		
Destroyer Tenders (AD)	350	1300
Combat Stores Ships (AFS)	150	500
Submarine Tenders (AS)	210	1000
Other (AE, AO, AOE, etc.)	75	350

D. Results of Effectiveness Analysis

Given the traffic volumes estimated in Chapter IV, the next step in a fully quantitative effectiveness analysis would be to perform calculations comparing the capacity of the different NAVMACS configurations to the offered load. Unfortunately, the term capacity as used in the NAVMACS program refers to a minimum value required to pass a performance test, and not to a maximum sustainable throughput.

However, experience with the V2(A+) system indicates that it has a saturation throughput of 12 million characters or more (five times the rated capacity). This value is high enough to provide all of our eleven ship classes with sufficient capacity, even under crisis conditions, to process all messages without unacceptable delays. Thus, we conclude in Chapter V that the V2(A+) system, or at most the V3(B) configuration, adequately meets the Navy's requirement for a terminal system.

We also consider the role of the V4 and V5 configurations in relation to the channels they use. Since V2 and V3 appear adequate on all ships, large message volumes alone do not justify V4/V5. Moreover, based on our approximate analysis, it appears that the CUDIXS channel may saturate well before the larger systems do. Thus, V4 and V5 may not provide significant additional improvements in delay or throughput compared to V2 and V3, because they will be operating downstream of a bottleneck.

Finally, we consider the effect of the NAVMACS program on the overall Navy communications system. Although good data on end-to-end (writer/reader) delays are scarce, what information we have seen indicates that the longest delays occur in the communications centers which send and receive messages. Thus, even a substantial reduction in the delay due to the automation of intervening steps may have only a small impact on overall delay. For Priority precedence messages, for example, our data indicates that even a nearly perfect automated system would reduce delays by only about 40 out of 220 minutes. A more realistic estimate for NAVMACS's impact would appear to be 20 minutes, or a reduction of about 10 percent.

In addition to providing greater channel capacity, NAVMACS V3, V4 and V5 provide an automated message entry capability via keyboard video display terminals (KVDT's). The principal advantage of this approach to message entry is the ease with which corrections can be made to messages. However, this may not be a cost effective solution since stand-alone units, similar to commercial word processing equipment, would be capable of providing equivalent editing features, and produce a machine readable output. This is an important consideration, because, as discussed in Chapter V, much of the increased cost associated with the V4 and V5 configurations is a result of their need to support a number of on-line terminals in a time-share mode. Recent advances in word processing technology have produced stand-alone units that appear to have significantly lower cost. Hence, the requirement for automated message processing capability in NAVMACS should be re-evaluated.

E. Scenarios Considered in the Cost Analysis

The effectiveness analysis discussed in the previous section provides information about the impact of the NAVMACS program on the Navy's ship/shore/ship communications capability. The purpose of the cost analysis is to estimate the resources required to purchase this capability.

The cost analysis provides estimates of the differential or avoidable costs associated with a scenario describing configurations and their installation schedule, compared to those costs that will be incurred under an assumed baseline scenario. The baseline we have used assumes that the Navy will incur costs for those NAVMACS configurations currently installed. Thus, spare parts costs for currently installed systems, while not yet technically sunk, represent costs that will not be avoidable for the life of the equipment. All the

costs presented in this report are additions to (or subtractions from) the costs of this base case. These costs, and other factors used in the analysis are discussed in Chapter VI.

Although we made every effort to obtain useful cost factors, much of the data concerning costs is not available. Also, the data we have obtained is of variable quality. Hence, some assumptions had to be made in the cost analysis. These assumptions are noted, and documented, in Chapter VI.

The decision problem associated with the NAVMACS program involves three related questions:

- What NAVMACS configurations should be developed and installed?
- On what aggregate ship classes should each of the configurations be installed?
- What should the implementation schedule be?

Each of the scenarios we have analyzed is designed to determine the costs associated with decisions made about these three questions. The development of these scenarios is discussed more fully in Chapter VII.

The characteristics of the six scenarios are summarized in Table I-5. The costs of alternative decisions regarding the three questions noted above are determined by comparing the costs associated with each of the scenarios.

The first scenario, referred to as the AMT scenario, is based upon the schedule of installations in the AMT of April 22, 1977.[1/] This schedule calls for the installation of NAVMACS equipment aboard 235 ships in Fiscal Year 1978 and beyond. The great majority of these

1/ Chief of Naval Operations, "Amalgamated Military and Technical Improvements," Washington, D.C., April 22, 1977.

Table I-5

Summary of Scenario Characteristics

Aggregate Ship Class	Scenario 1 AMT 4/77	Scenario 2 Full Capability	Scenario 3 V2 Only	Scenario 4 V1 - V3 Only	Scenario 5 V1 - V3 Only Postponement	Scenario 6 Large Ships Only
CV, CVN	V2, V3	V5	V2	V3	V3	V3
Large CG	V2	V5	V2	V3	V3	V3
Small CG	V2	V3	V2	V2	V2	V2
DD, DDG	V2	V2, V3	V2	V1, V2	V1, V2*	NONE**
FF, FFG	V2	V1, V2	V2	V1, V2	V1, V2*	NONE**
LCC, LHA, LPD, LPH	V2, V3	V3, V5	V2	V2	V2	V2
Small Amphibious	V2, V3	V1, V2*	V2	V1, V2*	V1, V2*	NONE**
AD	V2	V4	V2	V2	V2	V2
AFS	V3	V4	V2	V2	V2	V2
AS	V2	V3, V4	V2	V2	V2	V2
Other A	V2	V1, V2*	V2	V1, V2*	V1, V2*	NONE**
Total Installations By FY 1980	233	151	233	151	104	103
Total Installations By FY 1984 ***	304	310	304	310	310	131

* Current installations only.

** Except for current installations

*** In all scenarios except Large Ships (scenario 6) 310 ships ultimately receive NAVMACS. Only 131 ships receive NAVMACS in scenario 6.

installations will be of the V2 configuration. The V3 systems will be placed aboard carriers, AFS's, LCC's, LPD's, and LPH's with many of the V3's being upgrades of previously installed V2's. Of the 235 new installations, 158 are scheduled to be accomplished by the end of Fiscal Year 1980. This scenario represents the latest official schedule for the implementation of NAVMACS.

The second scenario, which we refer to as the Full Capability scenario, is based on a current, unofficial, schedule supplied to us through OP961E1. Included in this scenario are installations of all five configurations. Therefore, continued development of the V1, V4, and V5 configurations is required in this scenario. The schedule provided to us did not include a detailed assignment of configurations to aggregate ship classes. To provide comparability with the AMT scenario, we have made these assignments, on the basis of message volumes and command roles. Basically, the V5 configuration was assumed to be scheduled for installation on carriers, large cruisers, and most large amphibious warships. The V4 configuration is assumed to be designed for use on AD's, AFS's, and about one-half of the AS's. Small cruisers and some destroyers are provided with the V3 configuration in this scenario. The V1 is placed aboard small amphibious warships, ships in the other auxiliary aggregate ship class and on some frigates. The remaining ships, out of the 310 total (235 new installations) were provided with V2's.

The Full Capability scenario represents a somewhat different schedule of installations than the AMT scenario. Under the Full Capability scenario, only 76 new installations are made by the end of FY 1980. Therefore, the differences in the present value of cost between

this scenario and the AMT scenario will understate the cost differences due to the installation of the V1, V4, and V5 alone.

Our third scenario is a variant of the AMT scenario which assumes that all ships receive a V2 configuration instead of a mix of V2 and V3 systems. The schedule of installation is the same as that of the AMT scenario. The purpose of this scenario is to determine the additional cost of installing the V3 configuration aboard 36 ships.

The fourth and fifth scenarios are based on the schedule in the Full Capability scenario. The fourth scenario, referred to as the V1-V3 scenario, assumes that the V4 and V5 configurations are not developed. The V3 configuration is installed on carriers and large cruisers. Destroyers, frigates, small amphibious warfare ships, and other auxiliary ships are provided with V1 configurations. Until FY 1982, when the V1 is scheduled to be available, installations of V2 configurations continues on these ships. V2's are also provided on all other ships. This scenario allows us to determine the additional cost of developing and installing the V4 and V5 and installing the V3 and V2 configurations on ships with relatively small communications loads.

In the fifth scenario, called "Postpone", installation on all ships which could receive a V1 configuration is postponed until the FY 1982, when the V1 configuration is available. This scenario is designed to provide information on the cost of installing relatively large systems on ships solely because smaller, less costly systems, are unavailable.

The sixth, and final, scenario assumes that NAVMACS capability is provided only to large ships, with the V3 configuration installed aboard carriers and large cruisers and all other large ship classes

receiving a V2 configuration. Since this is the only scenario in which automation (i.e., NAVMACS) is provided to only a part of the surface Navy, it provides information on the cost of full automation.

F. Results of the Cost Analysis

Using the cost factors and assumptions discussed in detail in Chapter VI, we have estimated the costs of each of the six scenarios described in the previous section. As noted above, these are the differential costs above those that the Navy can realistically expect to incur as a result of the current NAVMACS installations. The results of our analysis are shown in Table I-6.1/ Shown along with the cost of each scenario are two measures of the capability provided in the scenario.

From Table I-6, the costs of the scenarios range from \$37 million to \$148 million. By comparing the costs of individual scenarios, the costs of particular decisions can be estimated. For example, installing only V2 configurations with the AMT schedule results in a savings of \$16 million. Similarly, if the V4 and V5 configurations are not developed, a savings of \$70 million can be realized. Postponing installation of NAVMACS on smaller ships reduces costs by \$14 million over the next most costly scenario. Finally, we see that the minimum cost of providing full automation is \$27 million.

1/ We have presented our results here as present values, discounted at 10%. Chapter VII provides more detailed data, including undiscounted total costs.

Table I-6
Total Discounted Avoidable Costs
(Millions of FY 1978 Dollars)

Scenario	Configurations Installed	No. of Ships with NAVMACS	Cost
AMT	V2, V3	310	$111
Full Capability	V1-V5	310	148
V2 Only	V2	310	95
V1-V3	V1-V3	310	78
Postpone	V1-V3	310	64
Large Ships Only	V2, V3	131	37

In Chapter VII, we also tested the sensitivity of our results to two specific factors: the economic life of all NAVMACS configurations, and the cost of the V1 configuration. Neither of these assumptions affect the ranking of the scenarios in terms of cost.

G. Recommendations

As we discussed briefly above, we have been forced to conduct this analysis with less information than we would prefer. Data on both the technical parameters and cost factors associated with NAVMACS is incomplete and, where necessary, we have made and documented assumptions based on other information. However, based on our

experience, we recommend:

1. Sufficient testing should be done by the Navy to determine the maximum capacity provided by each of the configurations. The maximum capacity of the smaller versions, not the minimum capacity of the larger systems, is the most important factor in determining effectiveness.

2. Steps should also be taken to obtain data on the costs associated with installing NAVMACS equipment aboard ship, with particular attention to (1) equipment costs and (2) impacts on shipboard manning that might result from automation.

Such information would provide the data required to complete a truly detailed cost-effectiveness analysis. However, given the wide differences in costs and the suggestive results from the effectiveness analysis, the conclusions listed above are, we feel, well supported and unlikely to change qualitatively. We urge the reader to consider the data, assumptions, and analyses in the following chapters carefully and critically so that these conclusions may be independently assessed.

CHAPTER II:

DESCRIPTION OF NAVMACS AND OPERATION

This chapter presents a brief description of current and proposed systems for message processing afloat. It includes the following sections:

- A description of current afloat communications methods
- A description of the Naval Modular Automated Communications System (NAVMACS) and afloat communications methods using NAVMACS' automated capabilities.

In reading our description, the reader should remember that the NAVMACS program is continually changing. Our description is intended to present it approximately as it is now, and some readers will find some of the details different from those they may remember from other documents. In order to prepare this description, we began by reviewing many of those documents. 1/ We then prepared a draft of this chapter and circulated it to Navy personnel in OP-961, OP-941 and NAVELEX. Their comments were incorporated in a revised draft, which they again reviewed. Thus, we believe that the following material, while brief, presents a reasonably accurate description of the current status of the NAVMACS program.

1/ The primary documents used were:

"Navy Training Plan for NAVMACS," NTP-E30-7503, enclosure (1) to CNO letter SER 992F2/70676, March 25, 1975.

Naval Electronic Systems Command, P4110.110, "Naval Modular Automated Communications System 'A+'," Integrated Logistic Support Plan," November 1976.

CDR. L.B. Garden, OP-941H, "Shipboard Message Processing Automation," March 30, 1977.

NAVELEX, "Overview of NAVMACS," September 27, 1974, preliminary draft of revision, 11 July 1977.

A. Current Communications Modes

Three manual communications modes are currently used for ship/shore/ship message communications:

- Broadcast (shore/ship)
- Terminations (two-way)
- Netted (small ship/shore)

The broadcast is operated over a 1200 baud [1/] UHF satellite circuit, with a 1200 baud HF radio circuit as backup. This circuit is subdivided into sixteen 75 baud channels. Full period terminations and netted communications are usually operated over HF radio links at 75 baud, but also can be accomodated by satellite links.

1. Operation

In broadcast mode communications, all ships monitoring a channel receive all the messages sent over it. Ships may monitor a general purpose broadcast channel and one or more additional channels, according to ship type (e.g., destroyers and frigates monitor a "destroyer" broadcast). Broadcast messages are screened by each ship: messages not on the "guard list" which controls the screening may be discarded by that ship. Because many ships monitor the same channel, the broadcast provides for simultaneous receipt of messages by multiple addressees. By sequencing the messages as they are sent, ships are provided with a ready check against missing a transmission.

1/ The speed of a digital communications channel in bauds is the number of times its state changes per second. In general, a baud is not equal to a bit per second. For the channels discussed in this report, which we are informed use a five bit Baudot (or Murray) code, there are 7.5 bauds/character.

Terminations are dedicated circuits between a ship and a shore station. For purposes of this analysis there are no differences between single channel terminations and multi-channel terminations. In both cases messages pass to and from the ship under the control of the operators at each end of the termination.

Netted communications use an itinerant ship/shore circuit to permit small ships (e.g., destroyers and frigates) to send messages to a shore communications station. All ships with messages to send join a single queue, with discipline maintained manually at the shore station. Operation of a netted circuit begins when a ship transmits a message notifying the station that it wants to send some traffic. The shore station assigns the ship a number corresponding to its queue position. Service is first-come-first-served, by precedence. When a message reaches the head of the queue the shore station requests transmission. If the message is garbled, repeat transmissions are requested until the message is received in useable form.

Because the shore station has many frequencies available, it is possible to assign several channels to one ship, providing the equivalent of several full-period terminations for a single ship, or of a full-period termination in the case of netted communications. However, manpower and equipment limitations restrict the use of this capability. Also, atmospheric conditions which cause distortion and fading often make a single frequency best for a single location.

Whichever communications mode is used, the way messages are routed ensures that a ship is seldom, if ever, working through two or more shore stations. For shore/ship communications, the NAVCOMPARS units are designed to route all messages addressed to a particular ship through one facility. Use of a single route preserves message precedences

and greatly simplifies the task of accounting for messages. For similar reasons, as well as manpower and equipment limitations on board, ship/shore messages are generally sent to only one shore station.

2. Structure of Current System

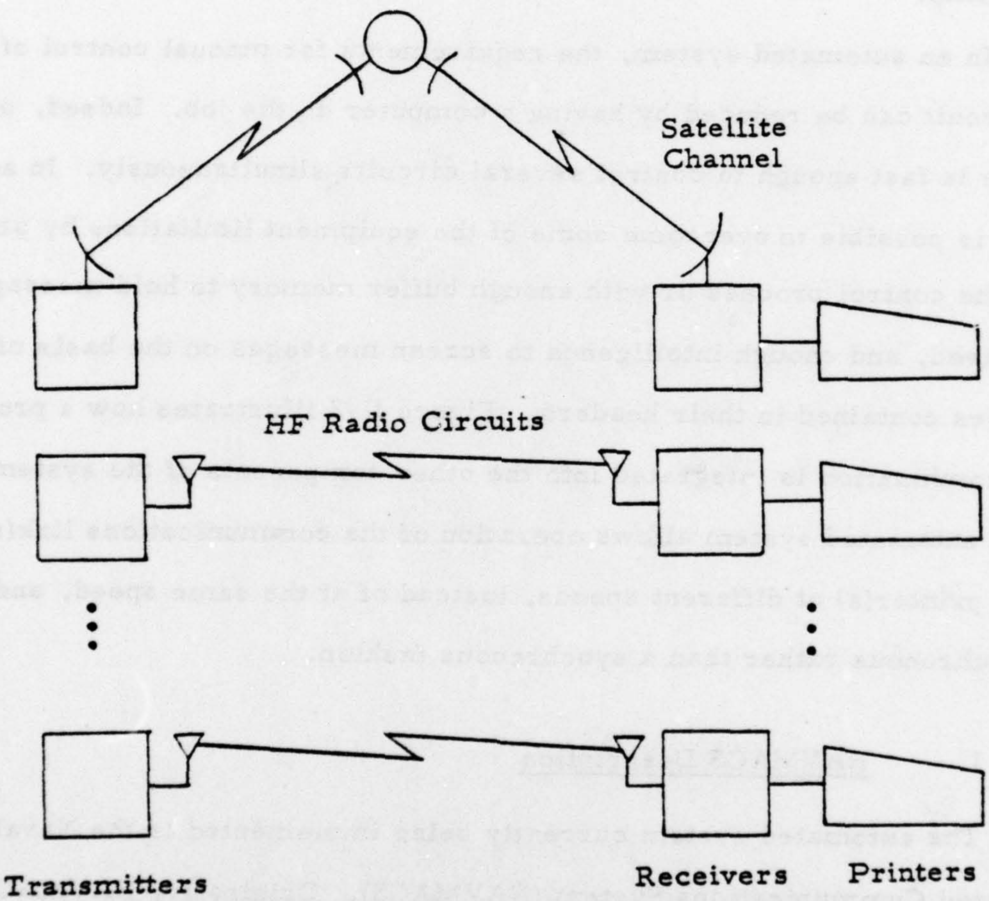
Although a variety of communications media and techniques are used, current Navy message communications are basically circuit-oriented. That is, messages are transmitted sequentially over one or more point-to-point connections, and are printed upon receipt without intermediate storage. Each circuit is limited by the speed of the circuit and the printer to essentially 75 baud.

This circuit-oriented arrangement is depicted in Figure II-1. As shown in the figure, several circuits can be used in parallel to increase the transmission rate of the system. Such parallel arrangements are used in the broadcast by assigning groups of ships to particular channels and by using overload channels when necessary. Also, larger ships (e.g., CV's and CG's) frequently have several full-period terminations in use simultaneously.

Delays in a system such as this occur when the speed of the circuit is insufficient for the traffic volume. Queues then build up at the transmitting end of the link or links. In the current system, the speed of message flow is constrained mainly by the limitation to 75 baud of much of the current equipment. In addition, the amount of shipboard manpower required to process messages may be considerable.

Figure II-1

Current System for Message Processing Afloat



B. Automated Message Processing and NAVMACS

The current system, discussed above, is largely a manual one. Personnel are required to monitor and coordinate each of the parallel circuits carrying messages from ship to shore or shore to ship. In addition, each circuit is individually limited in speed by the equipment contained aboard ship.

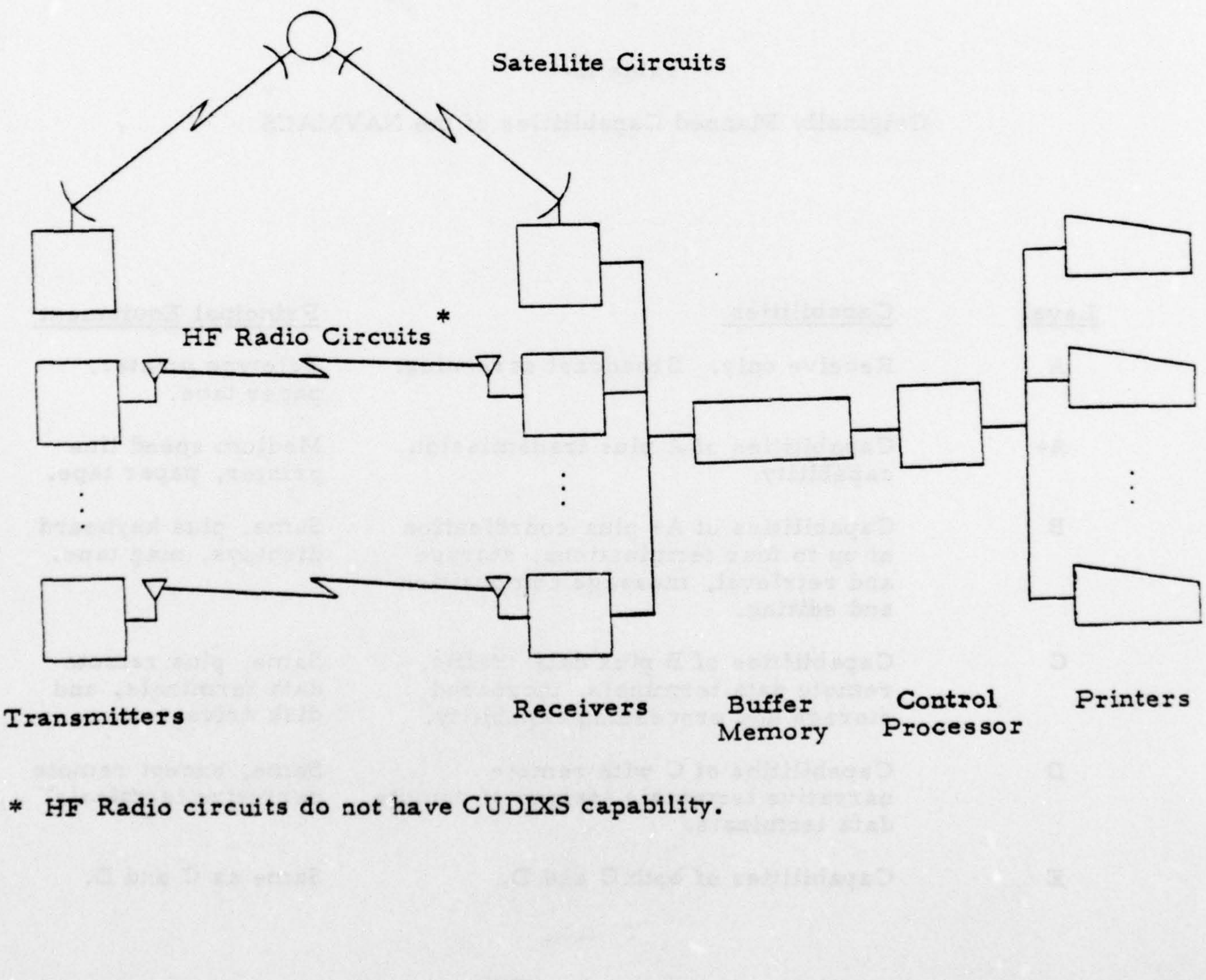
In an automated system, the requirements for manual control of each circuit can be reduced by having a computer do the job. Indeed, one machine is fast enough to control several circuits simultaneously. In addition, it is possible to overcome some of the equipment limitations by providing the control process or with enough buffer memory to hold messages as received, and enough intelligence to screen messages on the basis of the addresses contained in their headers. Figure II-2 illustrates how a processor/ buffer combination is integrated into the other components of the system. Such an automated system allows operation of the communications link(s) and the printer(s) at different speeds, instead of at the same speed, and in an asynchronous rather than a synchronous fashion.

1. NAVMACS Description

The automated system currently being implemented is the Naval Modular Automated Communications System (NAVMACS). Originally, NAVMACS was to consist of six levels of "sophistication." Each level built upon common components (hence modular), with higher level systems adding a new processing, storage, or distribution capability. The lowest level system

Figure II-2

Role of Message Processing Automation Afloat



* HF Radio circuits do not have CUDIXS capability.

(NAVMACS A) was to be a receive-only terminal that screened the broadcast and printed only those messages addressed to the ship while performing logging and journal entering of all broadcast messages to ensure against missed messages. The remaining versions of the NAVMACS added the capability of message transmission. Table II-1 indicates the capability of each level of the NAVMACS as originally conceived.

Table II-1

Originally Planned Capabilities of the NAVMACS

Level	Capabilities	Principal Equipment
A	Receive only. Broadcast screening.	Teletype printer, paper tape.
A+	Capabilities of A plus transmission capability.	Medium speed line printer, paper tape.
B	Capabilities of A+ plus coordination of up to four terminations, storage and retrieval, message composition and editing.	Same, plus keyboard displays, mag tape.
C	Capabilities of B plus data traffic, remote data terminals, increased storage and processing capability.	Same, plus remote data terminals, and disk drive.
D	Capabilities of C with remote narrative terminals instead of remote data terminals.	Same, except remote narrative terminals.
E	Capabilities of both C and D.	Same as C and D.

Over the past several years, the implementation of the NAVMACS has been continually delayed. (In one of the earlier NAVMACS documents, implementation of all six versions was scheduled for completion by mid-1977.) At the same time, R&D efforts were concentrated on two systems (A+ and B). Current plans 1/ are to install only these two systems through FY 1984. In FY 1982 and FY 1983, small ships are scheduled to receive "low cost suite" (AN/SYQ-7(V1), a descendant of NAVMACS A) and larger ships are to be upgraded from NAVMACS B (AN/SYQ-7(V3)) to one of several specialized systems. 2/ A comparison of current versions of NAVMACS is given in Tables II-2 and II-3. However, no installations of systems other than A+ and B are currently programmed.

In preparing these tables, we have gathered information from a number of published documents on NAVMACS, and have confirmed the details with OP-941H and NAVELEX. However, it should be noted that the V1, V4 and V5 configurations are still under development, and so details of their design are continually changing. Thus, while the tables provide as up-to-date and complete a view of the various NAVMACS configurations as possible, they should be regarded as a snapshot rather than a finished portrait.

2. Communications Using NAVMACS

Under automation with NAVMACS, there will be two important changes from the process described above. First, broadcast transmissions and terminations will take place over a satellite link. This increases the

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1/ Chief of Naval Operations, OP-436, "Amalgamated Military and Technical Improvements," Washington, D. C., April 22, 1977.

2/ CDR. L. B. Garden, OP-941H, "Shipboard Message Processing Automation," 30 March 1977. A detailed treatment of current schedules is contained in Chapter VII.

Table II-2

Automated System Characteristics

CURRENT SYSTEM DESIGNATION	SYSTEM NAME*	UNIT COST (THOUSANDS OF DOLLARS)**	PERSONNEL REQUIREMENTS (POSITIONS)	
			RM(2351)	ET(1453)
AN/SYQ-7 (V1)	LOW COST SUITE	100	1	1
AN/SYQ-7 (V2)	NAVMACS A+	174	1	1
AN/SYQ-7 (V3)	NAVMACS B	300	2	1
AN/SYQ-7 (V4)	LOGISTICS SYSTEM (NAVMACS C)	350	3	2
AN/SYQ-7 (V5)	FLAGSHIP SYSTEM (NAVMACS D/E)	898	3	2

* SUPERCEEDED NAME IN PARENTHESES, WHERE APPLICABLE.

** VALUES SHOWN REPRESENT THE LATEST FIGURES WE HAVE SEEN. ESTIMATES DO NOT INCLUDE INSTALLATION OR SPARES.

Table II-2 (Continued)

Automated System Characteristics

System Designation System Name	Terminal Equipment (excluding backups)							
	TTY (75 baud)	Line Printer (TT-624)	KVDT	Remote Sta. (KVDT + printer)*	Remote Data Station	Hi-Speed Paper Tape read/punch	Disk Drive	Mag-Tape Cassettes/ Drives
AN/SYQ-7 (V1)	1	0	0+	0	0	1	0	1
AN/SYQ-7 (V2)	1	2	0	0	0	1	0	1
AN/SYQ-7 (V3)	0	2	2	0	0	1	0	2
AN/SYQ-7 (V4)	0	2	3	0	1	1	0	2
AN/SYQ-7 (V5)	0	2	4	25**	1	1	1	2

* Printer speed not yet defined
** Upper limit. Actual value varies with installation.
\+ A KVDT may be defined here.

Table II-3

Automated System Performance

System Designation	Number of Channels			Message Processing Capacities			
	Broadcast	CUDIXS	Termin-ations	Messages Received/ Day	Messages Sent/ Day	Messages Combined/ Day **	On-Line Storage (days)
AN/SYQ-7 (V1)	2	1*	Torn tape	1000	100	1100	0
AN/SYQ-7 (V2)	4	1	Torn tape	1100	100	1200	0
AN/SYQ-7 (V3)	4	1	Torn tape †	1800	200	2000	3
AN/SYQ-7 (V4)	10 ††	1	10 ††	1800	200	3000	3
AN/SYQ-7 (V5)	16 ††	1	16 ††	4500	500	5000	3

* Transmit only

** Based on standard message of 2100 characters.

† Up to 4 full period terminations may be substituted for broadcasts channels.

†† Maximum value. Channels may be split between terminations and broadcasts as required.

transmission speed to 2400 baud, and also permits automatic control of the channel. As a result, a single high data rate broadcast will replace the current multi-channel broadcast. Second, an information exchange system (CUDIXS) will be available over the satellite. This system is intended to replace the netted communications mode currently used by small ships, as well as many of the terminations used by larger ships.

The Common User Digital Information Exchange System (CUDIXS) is an automated, polled satellite channel that can be operated in one of two ways. In the first, up to sixty ships can send messages to the shore. During each polling cycle (maximum length: two minutes) ships using CUDIXS either (1) announce that they are joining the system, (2) announce that they have a block of a message to transmit, or (3) transmit a block. The shore station coordinates the poll, and assigns slots for transmission to particular ships. As in the current netted operations, all ships using CUDIXS in this mode are essentially members of a single queue, served in round-robin fashion, by precedence. However, the higher speeds and lower error rates of the satellite channel, and the use of a variable block size, should make CUDIXS transmissions faster and more reliable than HF.

In the second mode of operation, up to ten ships can use the channel for two-way communication, while up to 50 additional ships continue in the transmit-only mode. For two-way communication, the channel is polled as before, with the shore station organizing shore/ship traffic and transmitting it at the appropriate time in the polling cycle. In this mode, CUDIXS substitutes for some full-period terminations.

Sufficient 25 kHz channels are included in the FLTSATCOM communications satellite to allow the simultaneous operation of two CUDIXS nets in each satellite's area of coverage. The satellite receivers connected to each NAVMACS have the capability to access either net. However, NAVMACS itself can operate only one CUDIXS at a time, as indicated in Table II-2.

3. Major Changes Associated With NAVMACS

As suggested in our discussion of Navy message processing, the principal effect of automation is to reduce message delays and/or increase message throughput. Using NAVMACS, these improvements occur because of the higher communications channel speeds and the automated control of the channel. On the larger configurations (V3, and especially V4 and V5), the use of KVDT's instead of TTY/torn-tape systems may also reduce the time needed to prepare a message for transmission.

The extent of the NAVMACS program's impact on the Navy's message processing system, however, depends on several factors. First, we need to know the capacity in the various NAVMACS configurations in relation to the traffic volumes they will be called on to process. Naturally, the system should have enough capacity to process the peak loads that occur under crisis conditions. However, once acceptable delays are achieved, the value of still more capacity may be questioned.

A second set of factors concerns the interaction of a NAVMACS system with the rest of the Navy's message processing system. This interaction is important because apparently large reductions in delays due to NAVMACS may not be realized if the effect of automation is to overload (or further overload) some other part of the system. This is because in a system like the Navy's one or two steps often constitute bottlenecks

which are responsible for most of the delay experienced by a message. Currently, the 75 baud teletype channels may constitute one of those bottlenecks. In this case, the NAVMACS program will have some effect in relieving this choke point. However, once the capacity of the ship/shore/ship channels increases beyond a certain point, some other part of the system will become a new bottleneck. Thereafter, additional capacity in NAVMACS will produce only a small additional improvement. Moreover, if the existing system is not a bottleneck even phenomenal reductions in delay due to the NAVMACS program will have little overall impact.

In order to address these two factors, we needed to know something about the loads on the existing system, and the probable loads under NAVMACS. (The two are different because the Navy's communications modes will change when NAVMACS terminals are available.) In the next chapter, we perform an analysis of existing traffic loads, using data supplied by NAVTELCOM on Navy ship/shore/ship messages. Our analysis allowed us to establish aggregate ship classes, with similar communications patterns and volumes, for use in comparing the performance and cost of the various NAVMACS configurations. In addition, our analysis provided us with estimates of current traffic, which we used in Chapter IV to predict future volumes under routine and crisis conditions.

CHAPTER III:
ANALYSIS OF CURRENT NAVAL MESSAGE VOLUMES

This chapter presents an analysis of data of Navy ship-shore-ship message traffic, in support of our study of Navy afloat automated message processing. The analysis has two objectives:

1. To estimate the volumes of messages and characters processed by Navy ships during routine operations, and
2. To identify classes of ships with similar traffic volumes.

The following chapter develops predictions of traffic volumes to be used in the overall analysis, including crisis traffic levels. These latter issues will, inevitably, require a number of assumptions to be made. In this chapter, however, we have tried to restrict ourselves to that part of the analysis for which reasonably hard data exist.

As was pointed out in Chapter II, different communications modes will be used when the NAVMACS terminals are available than is presently the case. Also, NAVMACS configurations must process messages not addressed to them, as well as those addressed to them. In order to make estimates of future volumes in Chapter IV, this chapter looks at traffic from several points of view. First, we consider messages addressed to the ship, and define a series of aggregate ship classes, and their message volumes. Second, we consider broadcast messages, which will form an important part of the message volume under NAVMACS.

Broadcast data also help us determine the lengths of messages, which are used in a third part of the chapter to estimate the total volume of traffic in characters. These estimates are important because loads expressed in characters per unit time are more important to an automated system than loads expressed in messages, because many of the computer's operations are carried out on each character.

The chapter is divided into the following sections:

a) Data sources -- which discusses the data used in our analysis.

b) Message volumes -- which develops estimates of daily message volumes by class of ship, and identifies similar classes.

c) Message lengths -- which develops estimates of message lengths.

d) Broadcast messages -- which considers the additional message volumes associated with broadcast messages to general addressees.

e) Traffic estimates -- which summarizes the traffic estimates developed in the earlier sections.

A. Data Sources

The primary sources of data for the analysis were a series of monthly reports on full period terminations between Navy ships and

shore stations, [1] prepared by Naval Telecommunications Command (NAVTELCOM). The period January-August, 1976, (the latest for which reports had been completed) was used. So far as is known, this period does not include either a crisis or a major exercise, and hence is representative of routine operations. Data on message lengths and broadcast transmissions were also provided, but our use of these items was more limited and straightforward than our use of the monthly report data, which we will discuss first.

1. Use of Monthly Reports on Terminations

As noted above, our analysis attempts to estimate the volume of messages from all sources (broadcast and terminations). With care, however, data contained in the monthly reports of terminations can be used to estimate the total traffic, because messages addressed to a ship are preferentially routed to a termination whenever one is available. Small ships (FF's, DD's and the like) must terminate for at least 48 hours each quarter for training, and during this period they normally send and receive all their messages over the terminated channel. Large ships are almost continually terminated, and are seldom addressed over the broadcast. [2] In either case, the message counts listed in the monthly reports for terminations include essentially all messages sent to or received from a ship during a day when it had an active termination. Dividing the number of messages

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1/ Commander, Naval Telecommunications Command, U.S. Department of the Navy, Naval Telecommunications Command, "U.S. Naval Communications Statistical Summary (U)" Ser 04/C1603 (1 March 1976), Ser 04/C1604 (31 March 1976), Ser 04/C1605 (7 May 1976), Ser 04/C1606 (9 September 1976), Ser 04/C1607 (22 December 1976), Confidential.

2/ As will be seen below, our sample of over 1,500 broadcast messages did not contain any messages addressed to CV's, or large CG's.

by the number of active days gives an estimate of the average daily traffic. The problem is that the monthly reports do not give the number of active days, and this quantity must be estimated from other data in the reports.

The way in which we have estimated active days may be illustrated by an example. Table III-1 illustrates the data abstracted from the monthly reports for an FF. As shown in the table, this ship was terminated during March, May and June of 1976. In March she was sent 59 messages (column 1), and 31 messages (column 2) were received ashore. Also, a total of five "channel-days" of terminations were recorded during March (column 3), where a channel-day indicates the use of one channel for all or part of one radio day.

Overall, a total of 714 useful observations from 222 ships were extracted from the monthly reports. The relatively low ratio of observations per ship (3.2) is explained by the fact that the smaller ships, which terminate infrequently, are also the most numerous.

In order to estimate the number of active days, we make use of the fact that terminations are usually established one at a time, and a second or third channel is only added when the traffic volume is heavy enough to warrant it. The monthly reports also contain data on the number of channel-days on each of several types of termination (single-channel HF, multi-channel HF, etc.). The largest of these numbers probably represents the total number of days when at least one termination was in operation and it was used as our estimate of active days. This figure is shown in column 4 of Table III-1. Columns 5, 6, and 7 then show how estimates of daily traffic volumes are calculated and summarized by a mean and a standard deviation.

Table III-1

Example of Data Extracted From Monthly Reports

Name MARVIN SHIELDS   Class FF

Month	Messages		Days Terminated		Message Rates (messages/day)		
	(1) Sent	(2) Received	(3) Total Channel Days	(4) Largest Channel Days on Single Medium	(5) Sent	(6) Received	(7) Combined
JAN	-	-	-	-	-	-	-
FEB	-	-	-	-	-	-	-
MAR	59	31	5	5	11.8	6.2	18.0
APR	-	-	-	-	-	-	-
MAY	41	13	2	2	20.5	6.5	27.0
JUN	32	42	2	2	16.0	21.0	37.0
JUL	-	-	-	-	-	-	-
AUG	-	-	-	-	-	-	-
MEAN					16.1	11.23	27.33
STANDARD DEVIATION					4.35	8.46	9.50

2. Sensitivity of Estimates of Active Days.

By taking the largest estimate of channel-days as our estimate of the number of days terminated, we inevitably introduce an error into our traffic estimates. For small ships, such as the FF shown in Table III-1, this error appears negligible because there is seldom any difference between the two numbers -- i.e., the same channel was probably in use at all times.

To assess the magnitude of the error for larger ships, we plotted both total channel-days and our estimate of total days of active transmission for the larger ships in our sample for the month of January. Figure III-1 shows this plot, along with an upper bound resulting from the fact that the number of active days cannot exceed either the number of channel-days or the number of days in the month. Also shown is a curve which depicts the average relationship between channel-days and active days which would be observed if the activity were completely random. 1/ Of course, activity is not random since terminations tend to be made for several days at a time. Because of this, the average relationship shown in the curve provides an approximate lower bound on the observed relationships.

As can be seen from the figure, the number of active days estimated by using the largest number of days terminated on any one type of channel is sometimes at its upper bound, and is seldom close to the approximate lower bound. In many of the remaining cases, examination

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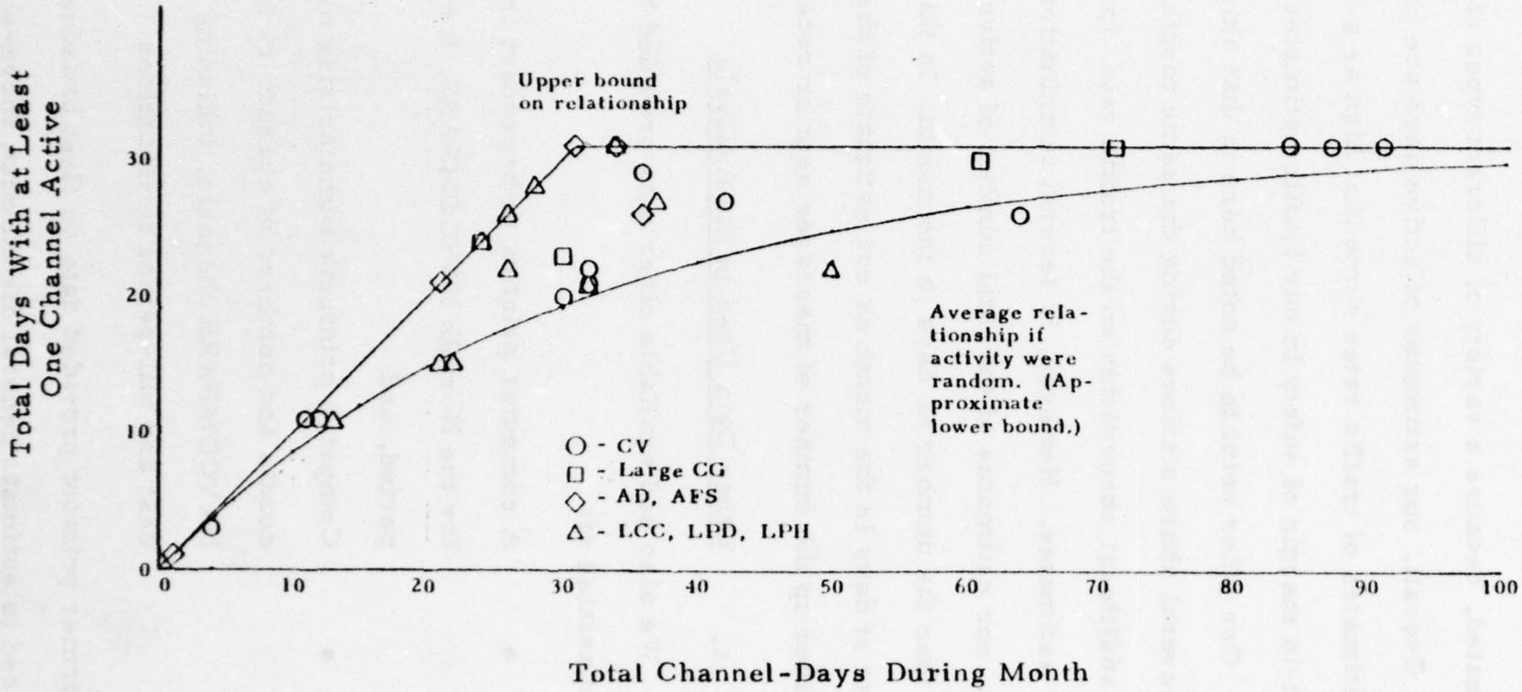
1/ If there are M days in the month, a completely random relationship would assign each of the N channel days independently to one of the days in the month, with probability $1/M$. Then the probability that there is at least one channel active on any given day is $P_N = 1 - (1 - 1/M)^N$, and the average number of active days in a given month is MP_N, which is plotted in the figure. Notice that, since we have not accounted for the limited number of channels available to a ship, this average is biased upwards.

Figure III-1

Relationship Between Channel-Days and Days of Active Transmission for January, 1976



of the data suggested that the estimate understated the number of actual days terminated, because a variety of different types of channel were used by the ship. Overall, our estimates of active days are probably somewhat low, and our estimates of traffic rates somewhat high as a consequence. This provides a built-in margin of safety in our traffic estimates.

One other point to be noted here is that ships are sometimes terminated with several shore stations during the same month. In general, this gives us an additional observation on the traffic rate, increasing the sample size of our estimates. However, if several terminations are reported in the same month, our estimates of the total number of active days may sum to more than the number of days in the month. In this case, we used the number of days in the month as our estimate of the number of active days, and added up the number of messages sent or received from all terminations.

3. Other Data Used in the Analysis

We also had available other data provided by NAVTELCOM. These data consisted of:

- A computer printout of broadcast traffic data for the Norfolk NAVCOMPARS, for a 24-hour period, and
- Computer printouts summarizing message counts and numbers of characters for NAVCOMPARS channels, including both broadcast and full-period terminations.

The former printout provided data on fleet broadcast message traffic which was used to estimate general distribution shore-ship traffic. The latter printout was used to develop estimates of message lengths. No

anomalies were noted in the data, and we believe it provides a good basis for estimating peacetime message lengths.

The 24-hour broadcast message summary (first item above) was a by-product of tests conducted by NAVTELCOM on the Norfolk NAVCOMPARS early this year. The printout contains message sequencing and timing information not of concern here, along with an identification of the addressee of the message. This addressee information was used to identify ships (or other addressees, such as AIG's) and allowed us to tabulate the number of messages addressed to each addressee. 1/

B. Message Volumes

The monthly report data were used as described above to estimate the average daily message volumes for each ship. The data were then aggregated by ship class, and examined to see which classes of ship seemed to have the same overall traffic patterns. Some statistical techniques, discussed below, were used to test for similarities.

1. Definition of Ship Classes

As a result of the analysis discussed later in this section, it was found that the ninety-odd formal ship classes could be adequately represented by eleven larger groups, which we have called "aggregate ship classes:"

1/ NAVTELCOM personnel tell us that the day was, in their opinion, a typical one. Also, they are aware of no other data on the broadcast.

1. Carriers (CV, CVA, CVN, CVT)

2. Larger cruisers (CG and CGN)

3. Smaller cruisers (CG and CGN)

4. Destroyers (DD and DDG)

5. Frigates (FF and FFG)

6. Larger amphibious warfare ships (LCC, LHA, LPH, LPD)[1/]

7. Smaller amphibious warfare ships (LSD, LST, LKA, etc.)

8. Destroyer tenders (AD)

9. Combat stores ships (AFS)

10. Submarine tenders (AS)

11. Other auxiliaries (AO, AE, AOE, etc.)

Among combatants, all carriers have similar communications patterns; however, these vary depending on whether or not an air group is embarked. Larger cruisers (specifically, CG's 4, 5, 10 and 11) have the largest traffic volumes of any class, due to their role as fleet flagships. Smaller cruisers handle much lower traffic volumes, and form a statistically separate class from the larger CG's. Destroyers and frigates can be grouped into two classes.

For amphibious warfare ships, it was initially thought that the larger command-oriented ships (LCC, LHA, and LPD-7 through 15) would have a different traffic pattern from medium-sized vessels (LPD-1 through 6, and LPH). However, we found no statistically significant difference between these two groups. Thus, amphibious warfare ships are grouped into only two classes.

1/ AGF-3 (former LPD-3) was also included in this category.

On the other hand, auxiliary vessels have very heterogeneous traffic patterns. AD's, AFS's and AS's each have a distinct distribution of traffic volumes, and the fourth class of vessels (AE, AO, AOE, etc.) would have been further disaggregated if there had been enough data on separate classes to permit it.

2. Estimated Message Volumes

Table III-2 and III-3 show the estimated daily message volumes for these eleven ship classes. Table III-2 shows the mean and standard deviation of messages received by the ship and sent from the ship separately. Table III-3 shows these quantities for the combined message volume, and also presents an estimate of the 90th percentile of the distribution, i.e., the daily message volume that is exceeded only one time in ten. The number of observations for each ship class is also given in this table.

As can be seen from both tables, the standard deviations of message volumes are about the same size as the average message volumes. As will be seen below, one cannot regard the underlying distributions as drawn from a Normal (bell-shaped) distribution. Indeed, as tabulated, these standard deviations indicate tremendous possible variability for routine operations.

However, some of the randomness suggested by the standard deviations given in these tables is illusory. This is because the observed variation in message volumes is due to factors such as:

- Seasonal or quarterly cycles in message volume,
- Differences in volume due to location (LANT vs. MED, for example),
- Differences in operational assignment, and
- Differences in communications center procedures.

Table III-2

Estimated Daily Message Volumes

	Received		Sent	
	Average	Standard Deviation	Average	Standard Deviation
Combatants				
CV, CVN	282	207	105	78.6
Larger CG, CGN	427	303	63.8	38.4
Smaller CG, CGN	84.0	105	29.5	25.4
DD, DDG	34.4	43.1	20.6	19.9
FF, FFG	20.9	23.0	20.6	15.6
Amphibious Warfare Ships				
LCC, LHA, LPD, LPH	136	120	42.7	35.0
Other (LKA, LSD, LST, etc.)	30.8	29.6	16.7	15.2
Auxiliaries				
AD	204	128	24.3	10.5
AFS	87.5	64.5	30.9	17.5
AS	119	98.8	21.7	15.6
Other (AE, AO, AOE, etc.)	64.1	117	18.1	17.3

Table III-3

Estimated Number of Daily Messages

(Combined Send and Receive)

	Average	Standard Deviation	90th Percentile	Number of Observations
Combatants				
CV, CVN	386	278	814	133
Larger CG, CGN	491	332	865	39
Smaller CG, CGN	114	120	265	54
DD, DDG	55.1	55.9	133	94
FF, FFG	41.5	30.5	88	79
Amphibious Warfare Ships				
LCC, LHA, LPD, LPH	179	147	405	143
Other (LKA, LSD, LST, etc.)	47.5	40.5	91	39
Auxiliaries				
AD	228	134	500	30
AFS	118	69.7	199	21
AS	140	113	273	23
Other (AE, AO, AOE, etc.)	82.2	130	178	59

Since we cannot distinguish between these factors, our calculations necessarily use an overall average and standard deviation.

The cause of the large calculated standard deviation can be illustrated by a simple model in which only two of the factors listed above are considered. Suppose that the communications volume on a ship is x_{ij} , where $i = 1, \ldots, n$ indexes ships within a class and $j = 1, \ldots, m$ indexes time periods. This volume is composed of (1) a random component associated with the ship, and (2) a deterministic component that varies over time according to a seasonal cycle. For simplicity, we assume the cyclical component makes no net contribution to the volume. (I. e., it has a zero average value.) The total volume may be written:

$$x_{ij} = x_i + x_j$$

In order to study peak volumes, we are interested in the probability distribution of the ship-specific component, x_i , because the maximum of the time-varying component x_j can always be added in later.

However, since we cannot separate the ship-specific component from the time-varying component, suppose we calculate averages and standard deviations as in Tables III-2 and III-3. These give: 1/

$$E(x_{ij}) = E(x_i) + E(x_j) = E(x_i)$$

$$E(x_{ij} - E(x_{ij}))^2 = E(x_i - E(x_i))^2 + E(x_j - E(x_j))^2$$

1/ The second formula given assumes the independence of x_i and x_j. If these two quantities are dependent on each other the formula would be more complicated, but the conclusion following the formula would be unchanged.

where the notation E(·) indicates that an averaging operation is to be performed. Notice that, although $E(x_{ij})$ can be used to estimate $E(x_i)$ we cannot solve for the desired quantity, $E(x_i - E(x_i))^2$, unless other data allows us to find $E(x_j - E(x_j))^2$ separately. Moreover, if the left-hand-side quantity is used alone, we will overestimate $E(x_i - E(x_i))^2$ because both terms on the right-hand-side are positive.

The problem analyzed by this model is not wholely conjectural. Using a technique known as Analysis of Variance we tested our observations on aircraft carriers to determine the effect of variations between ships, relative to variation within a ship. As discussed in the footnote, we found some evidence that there was significant inter-ship variation. 1/ Overall, we believe that the effect demonstrated by the example causes the standard deviations in Tables III-2 and III-3 to overstate the standard deviation of message volumes. We will return to this issue when we estimate traffic loads during peak periods.

1/ The test was conducted on CV-41 and above, treating each ship as separate category in a one-way classification scheme. The F-value associated with a test of equal means was $F_{12,76} = 6.97$, which is very significant. ($Pr[F > 6.97] = 2.5 \times 10^{-8}$.) However, this test is sensitive to heteroskedasticity and non-Normality, both of which are present in the data. In an attempt to correct for the heteroskedasticity, the test was re-run using the square roots of data values. This transformation is helpful when, as appeared to be the case here, the variances are proportional to the expected values. The result gave $F_{12,76} = 7.30$, with $Pr[F > 7.3] = 1.2 \times 10^{-8}$. Both these results should be regarded with suspicion, however, since the data is by no means Normal. For discussion, see M. G. Kendall and A. Stuart, The Advanced Theory of Statistics, Vol. 3 (3rd edition), Chapters 35-37.

If the seasonal cycles used in these illustrations were the only problem, it might be possible to adjust our estimates of the standard deviation for these factors. However, since we do not know all the causes of these factors, it is impractical to make any meaningful adjustment to the figures in Tables III-2 and III-3.

As also can be seen from Table III-2, ships of all classes receive more messages than they send. Command ships (larger cruisers and amphibious warfare ships, and destroyer and submarine tenders) receive from three to eight times as many messages as they send.

Table 3, showing the combined message volumes, shows the CV's and larger CG's to be the platforms with the largest message volume (average traffic 400-500 messages per day, 90th percentile roughly 850 messages per day). Next in volume come the larger amphibious warfare ships and destroyer tenders (mean roughly 200 messages per day, 90th percentile 400-500 messages per day), followed closely by the AFS's and AS's and the smaller CG's (averaging roughly 125 messages daily, with a 90th percentile of 200-250 messages per day). Finally, the FF's, DD's and other amphibious warfare ships and auxiliaries all process fewer than 100 messages daily, on average, and have 90th percentiles of 100-150 messages per day. Within the latter group, FF's have the lowest average volume, roughly 40 messages per day.

3. Detailed Comments

In addition to the summary statistics presented above, the following figures 1/ present histograms showing the distribution of message volumes by

1/ Figures III-2 and III-3 through III-10.

class of ship. Some of the patterns revealed by these figures are discussed below, along with the results of the statistical tests of classes.

a. Statistical Techniques Used to Identify Classes

As can be seen immediately from the figures, we are not dealing here with distributions which follow a bell-shaped, **Normal distribution.** Thus, the usual t-tests and F-tests for the equality of means or variances are inappropriate ways to identify common classes because they assume Normality.

Instead of using these tests, we tested the histograms from two classes directly, using a Chi-squared (χ^2) test of the hypothesis that the same probability distribution generated both histograms. This test procedure was neither the most statistically efficient nor the most elegant that we could have chosen. For example, since it involves a grouping of the data it is inferior to more complicated tests which do not require grouping. 1/ However, the Chi-squared test is fairly reliable, and its results in the cases presented below appear reasonable in the light of the additional information we have about the different ships (such as their typical missions and modes of operation).

1/ See, e.g., M.G. Kendall and A. Stuart, op. cit., Chapters 30 and 33.

b. Carriers

As an example of our approach, consider the aircraft carriers, for which a histogram is shown in Figure III-2 below. Originally, it was thought that the newer and larger carriers (with hull numbers CV-59 and above) might have different traffic volumes than the older or smaller carriers (CV's below 59, CVT, etc.). To test for this difference, histograms of message volumes were prepared for each of the two classes. After combining some cells so that there were at least five observations in each one, [1] the calculated Chi-square statistic was 6.84, with six degrees of freedom (written $\chi^2_6 = 6.84$). Since the probability of obtaining a value of χ^2 at least this large by chance alone was 0.336 (making the actual observation rather likely), we could not conclude that there was a statistically significant difference between the two tables. In other words, based on the data available older and newer carriers had the same overall distribution of message volumes.

This statistical observation, however, does not end the story. Examination of the carrier data indicated a possible secondary peak of higher than usual activity. This latter peak involves 400-700 messages per day, and can just be seen in Figure III-2. This peak might be associated with the activity taking place aboard ship when an air group is embarked. Thinking that such activity would follow a regular pattern, with several consecutive months of higher activity alternating with

1/ This is a requirement of the Chi-squared test, as used here.

several consecutive months of lower activity, we plotted pairs of monthly message observations for CV-41 and above, as shown in Figure III-3. If there were alternating periods of higher or lower activity, we would expect to see two clusters of points on the graph, lying roughly along the 45° line. No such clustering is apparent in the figure, although there appears to be some tendancy for high or low activity months to follow one another because points do lie near the 45° line. Thus, we cannot be sure that the secondary peak observed in Figure III-2 is due to any periodic phenomenon.

c. Larger and Smaller Cruisers

Figure III-4 shows a situation where a difference in message volumes was confirmed by the Chi-squared test. As shown, CG's 4, 5, 10 and 11 have a much different distribution of messages from the smaller ones. Smaller CG's have a distribution which falls off rapidly from a peak of 0-100 messages per day. Larger CG's have a bi-modal distribution, with one peak coinciding with the smaller cruisers' distribution and a second peak of 700-800 messages per day, probably corresponding to periods when they act as fleet flagships. In this case the value of χ^2 calculated was 34.23 with 3 degrees of freedom. The corresponding probability of observing this value (or a larger one) if the two distributions were equal is less than one in ten million--an event so unlikely that we have little trouble accepting the hypothesis that the two distributions are indeed different.

d. Frigates and Destroyers

As shown in Figures III-5 and III-6, the shapes of the message volume distrubitons for frigates and destroyers are similar. However, the

Figure III-3

Relationship Between Paired Months for CV-41 and Above

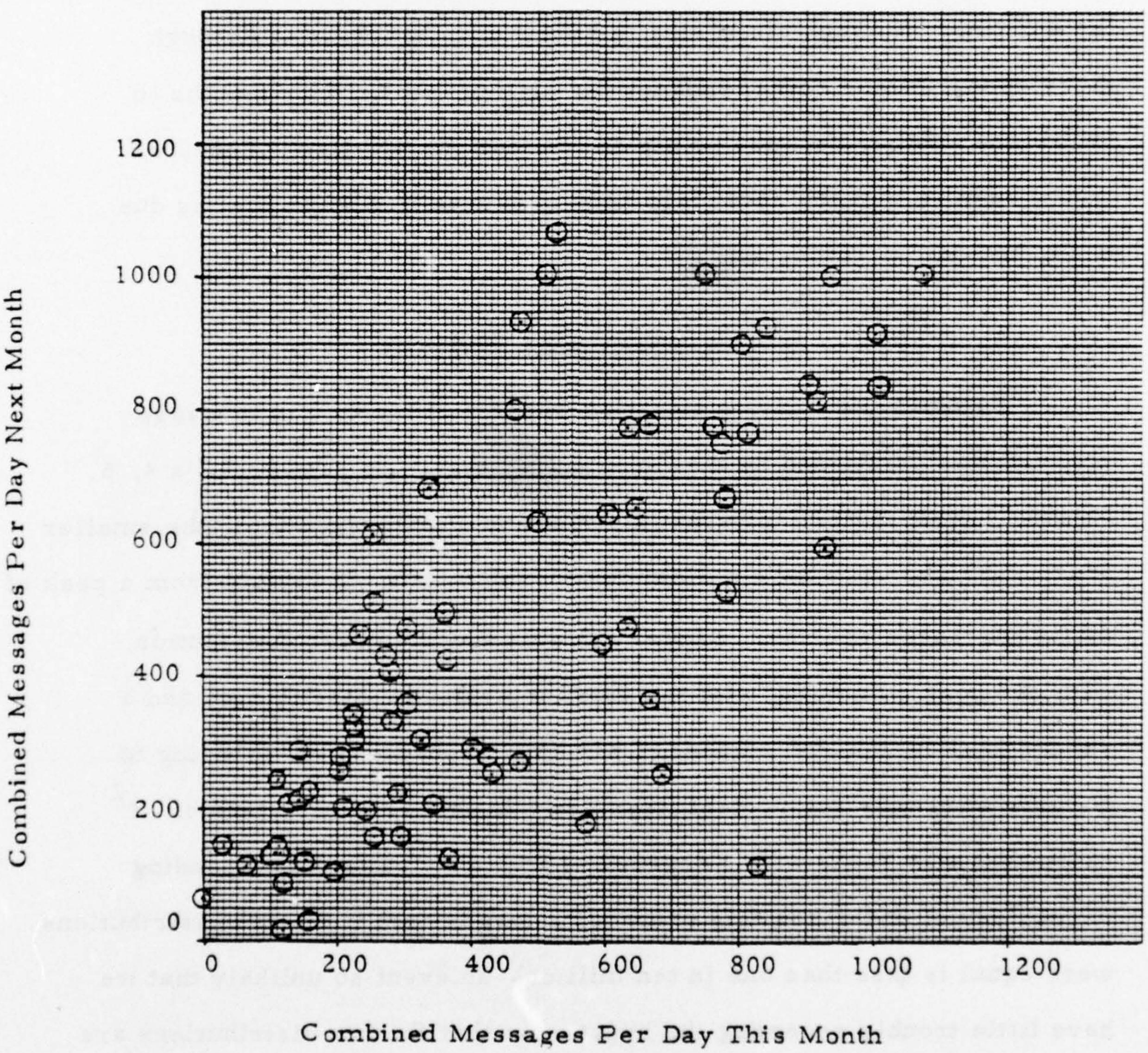


Figure III-2

Distribution of Message Volumes for Aircraft Carriers

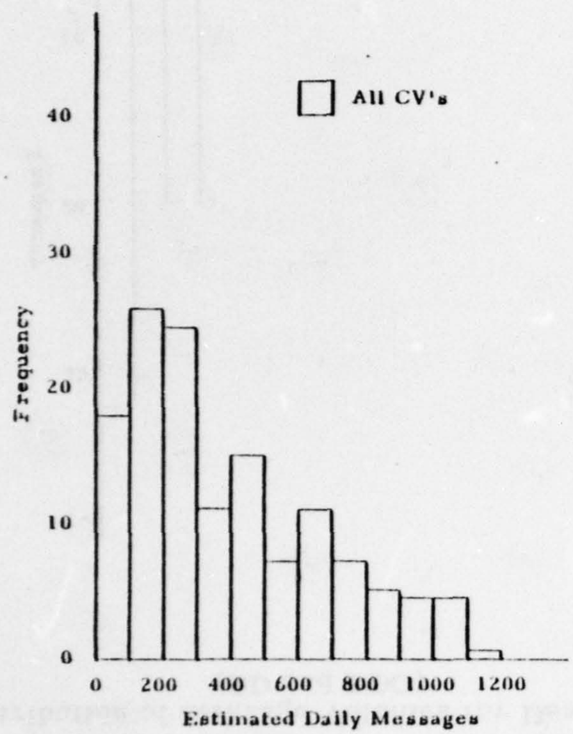


Figure III-4

Distribution of Message Volumes for Cruisers

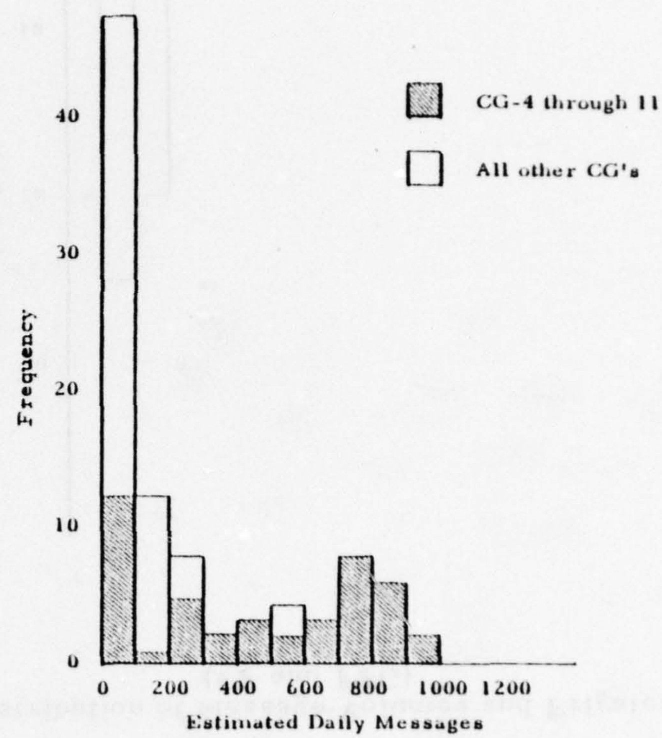


Figure III-5

Distribution of Message Volumes for Destroyers
(DD and DDG)

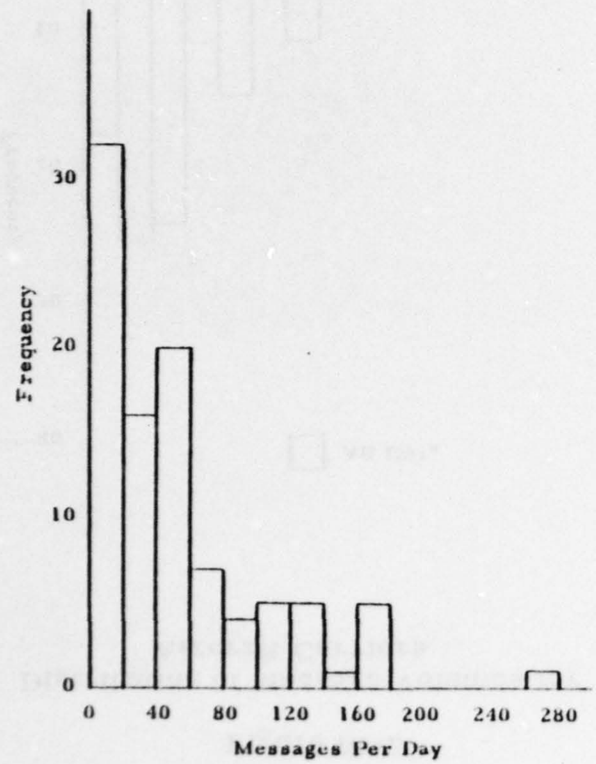
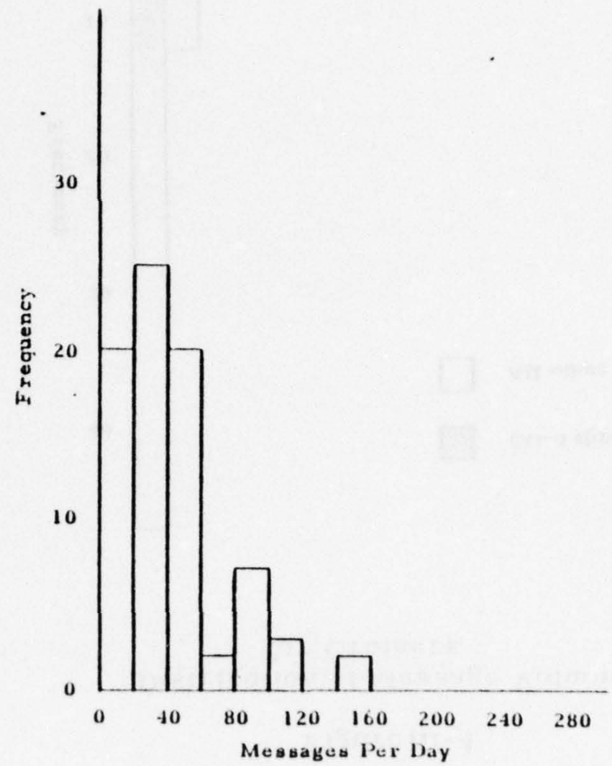


Figure III-6

Distribution of Message Volumes and Frigates
(FF and FFG)



two classes are indeed different, for the value of χ^2 is 113.7 with 4 degrees of freedom. ($Pr[\chi^2 > 113.7] < 10^{-9}$). Also, there was no obvious pattern of the transmissions within either class to indicate that we were combining different types of activity in the same histogram.

e. Amphibious Warfare Ships

It was initially thought that the larger amphibious warfare ships (LCC, LHA and LPD-7 to 15), which sometimes serve as command ships, would have a different distribution of message volumes than the medium-sized ships (LPD-6 and below, and LPH). However, the value of χ^2 was only 2.737 with 6 degrees of freedom, which does not indicate a significant difference between the two groups. ($Pr[\chi^2 > 2.737] = 0.841$)

However, as was the case with larger cruisers, we can see a secondary peak in the message volume distribution in Figure III-7. While the largest concentration is below 200 messages per day, this peak shows a level of 350-500 messages per day, and may indicate the level of activity to be expected when these ships serve their command function.

Figure III-8 shows the distribution of message volumes for the other amphibious warfare ships. With only 39 observations, the number of observations on any individual class was not large enough for additional disaggregation.

Figure III-7

Distribution of Message Volumes For Larger Amphibious Warfare Ships (LCC, LPD, LPH, LHA)

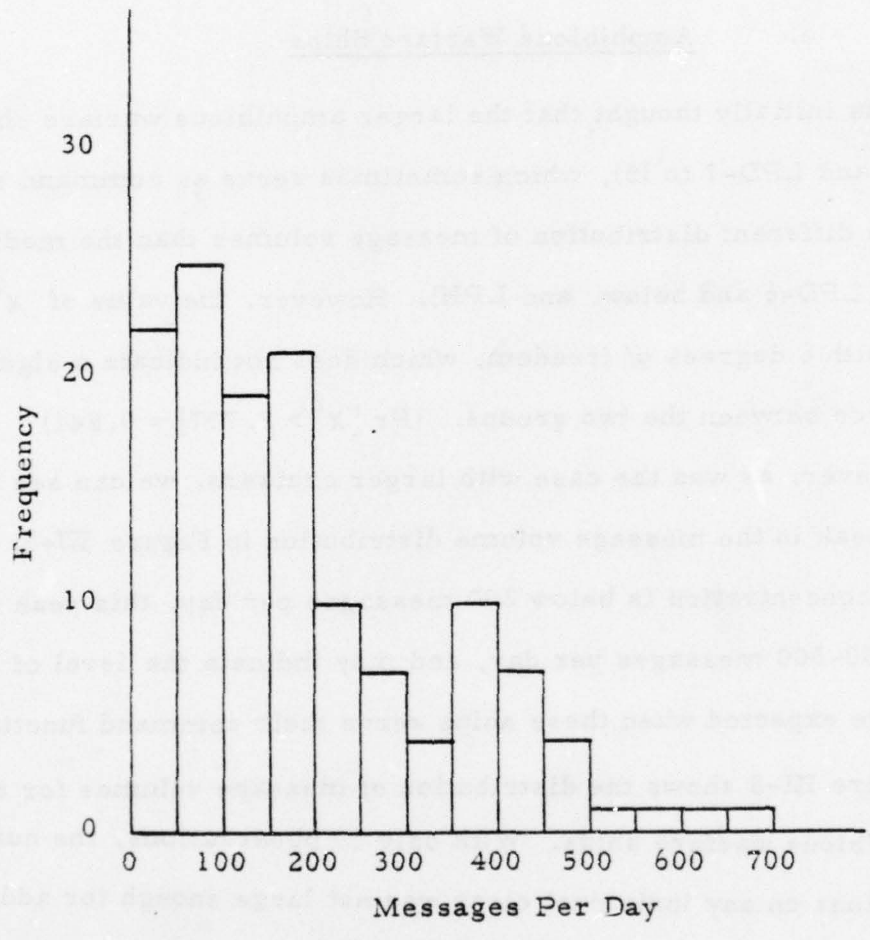
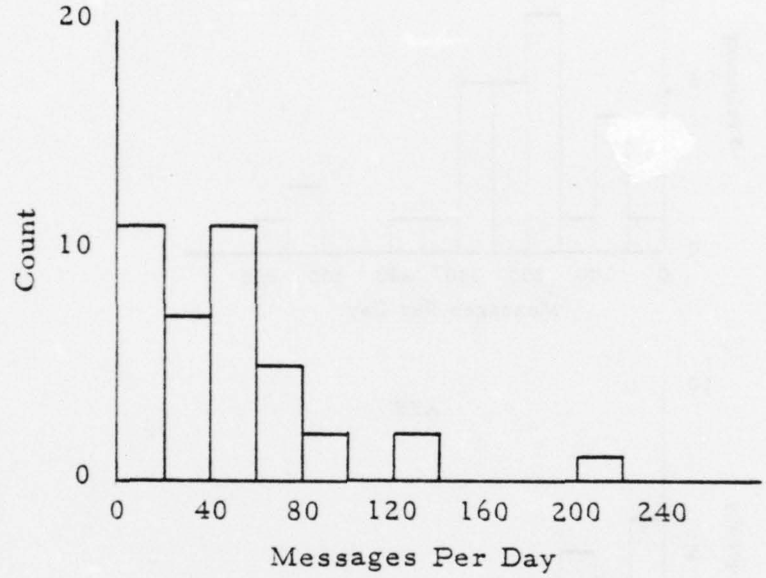


Figure III-8

Distribution of Message Volumes For Smaller Amphibious Warfare Ships (LKA, LSD, LST, etc.)



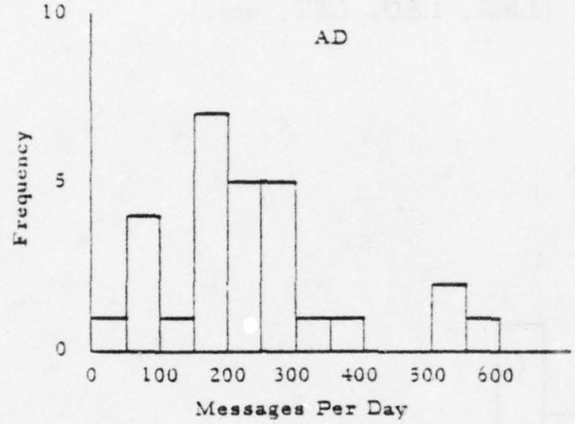
f. Auxiliary Vessels

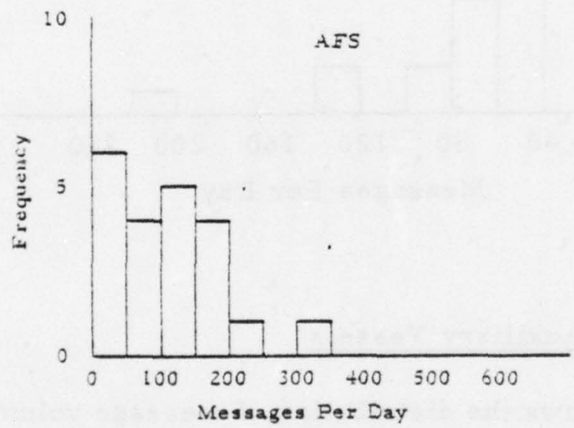
Figure III-9 shows the distribution of message volumes for destroyer tenders, combat stores ships and submarine tenders. A test of equality among all three classes gave $\chi^2_4 = 9.62$, which is significant at the five percent level, so we reject the hypothesis of equality. ($\Pr[\chi^2 > 9.62] = 0.047$)

The histogram for the other auxiliary vessels is shown in Figure III-10. As can be seen, there are several large outliers in this distribution; the three largest are all due to the same AR, which investigation showed to have

Figure III-9

Distribution of Message Volumes for Larger Auxiliaries





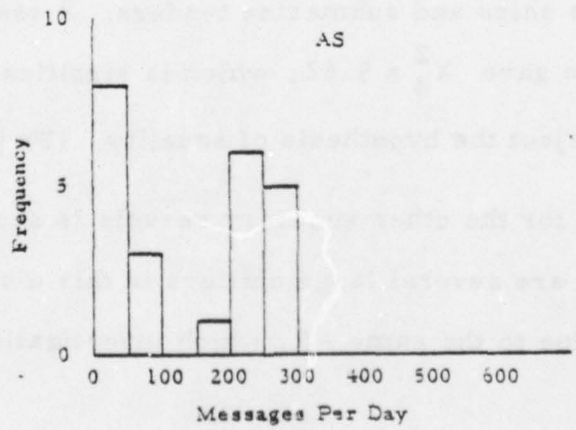
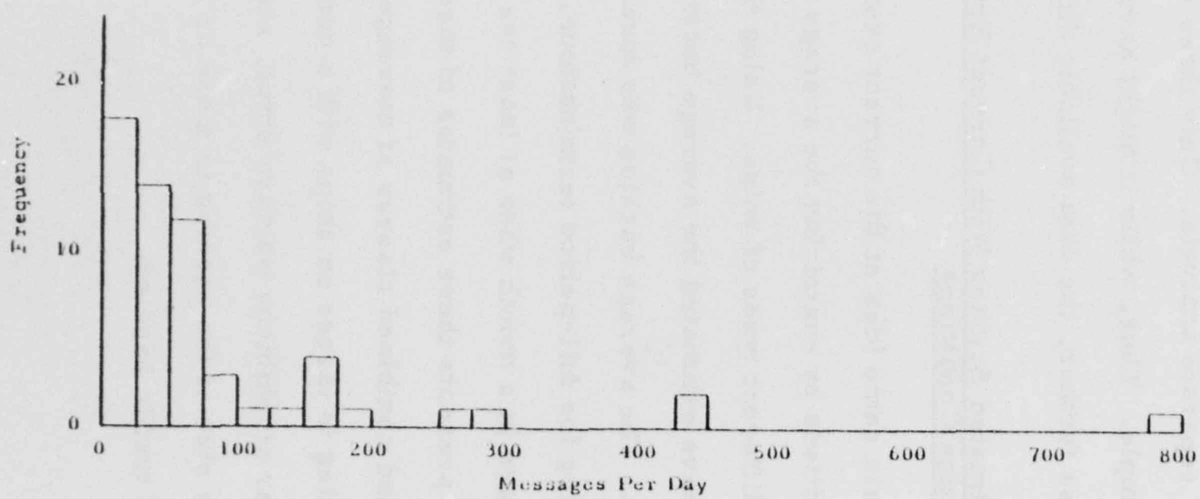


Figure III-10

Distribution of Message Volumes for Smaller Auxiliary Ships

(AE, AOE, AO, AR, etc.)



been flying a flag at the time. However, no one class provided enough observations for a separate analysis. Only three terminations by AOE's were recorded, for example. Thus, while it might have been desirable to disaggregate this class further, the data available did not allow this to be done.

4. Estimated Backlog With Current Equipment Under Routine Conditions

We can obtain some idea of the current system's performance under routine conditions by examining the average backlog of untransmitted messages aboard different types of ships. Using the monthly reports of terminations, we have estimated the average backlog for the eleven aggregated ship classes. The average backlog was measured by taking the reported monthly total backlog for full-period terminations, and dividing by our estimate of the number of days in a month when at least one termination is active.

Table III-4 presents these estimates of message backlog for shore/ship, ship/shore and combined classes of message. As can be seen from the table, the backlog is larger on ships with a command capability (CV's, larger CG's, larger amphibious warfare ships, and so forth), than on other ships. In fact, the size of the backlog is more or less directly related to the total volume of traffic handled.

Table III-4

Average Daily Backlog of Messages

Ship Class	Shore/ Ship	Ship/ Shore	Combined
Combatants			
Carriers (CVA, CV, CVN, CVT)	13.25	1.12	14.37
Larger Cruisers (CG & CGN)	11.96	0.53	12.49
Smaller Cruisers (CG & CGN)	3.93	0.11	4.03
Destroyers (DD & DDG)	0.71	0.04	.75
Frigates (FF & FFG)	0.58	0.00	.58
Amphibious Warfare Ships			
LCC, LHA, LPH & LPD	5.98	0.33	6.31
Other (LKA, LSD, LST, etc.)	0.23	0.16	.40
Auxiliaries			
Destroyer Tenders (AD)	1.38	0.11	1.47
Combat Stores Ships (AFS)	5.72	0.20	5.92
Submarine Tenders (AS)	3.83	0.00	3.83
Other (AE, AO, AOE, etc.)	1.10	0.05	1.15

C. Message Lengths

For record communication, the number of characters sent and received is as important as the number of messages. In order to estimate daily character volumes for the eleven ship classes defined in the previous section, we separately estimated message length statistics using several data sources. The first of these is a computer tabulation made available by NAVTELCOM. The printout included data on message lengths, broadcast channels, and on certain full-period terminations to particular ships. These data were daily values (i.e., total characters, divided by corresponding total messages sent during the day.)

Table III-5 summarizes the results of these tabulations, showing the average and standard deviation of message length for both ship-shore and shore-ship messages, as well as the number of observations on which these statistics are based. Because the data was compiled at the NAVCOMPARS sites, message lengths shown include addressee information.

As can be seen from the table, ship-shore messages are generally shorter than shore-ship messages. While the standard deviations of message lengths for shore-ship messages do not appear to depend on whether broadcast or full-period termination data were used, there is a difference for ship-shore messages.

In order to develop overall estimates of message length distributions, we combined the observations on broadcast messages and full-period terminations. For shore-ship messages, an F-test and t-test indicate no significant difference in message length between these two classes, [1/] and so we combined them to obtain an overall shore-ship average message length of 1497. In our calculations, the average was

1/ $F_{71,246} = 1.23$ and $t_{315} = 1.637$.

Table III-5

Message Length Statistics

	Ship-Shore Xmissions (Char/Msg)			Shore-Ship Xmissions (Char/Msg) 1/		
	Average	Standard Deviation	Number of Observations	Average	Standard Deviation	Number of Observations
Broadcast						
Norfolk	441.00	55.42	30	1467.2	256.14	130
Honolulu	429.26	54.52	27	1502.2	276.00	116
Terminations						
Carrier	470.30	165.76	23	1432.3	256.56	24
AR	504.38	242.00	13	1382.9	201.24	13
LPD 2/	472.50	137.28	6	1584.4	301.44	19
LPH 2/	539.67	209.58	6	1800.2	235.26	15

Notes: 1. Estimated at 6 characters per word.

2. Flag on board.

rounded to 1500 characters. (This is about 250 words, using six characters per word.)

An F-test indicated that ship-shore transmissions via broadcast and terminations had unequal variances, as is also evident from the table. However, a Behrens-Fisher test indicated equal means. [1/] Thus, a mean length of 460 characters for ship-shore messages was used for estimates of traffic volumes.

In our message length estimates given above, we have included characters that make up the message text and address, as well as "invisible" characters that form an integral part of the message but are not actually printed. The invisible characters include carriage returns and other characters which control the format of a printed message. Blank spaces, appearing in a line of text anywhere between the left margin of a page and the carriage return for that line, are considered to be "visible" characters. It has been estimated (informally) by NAVTELCOM personnel that approximately 85 percent of all of the characters transmitted in a message are visible.

In order to determine the length of the text and address portions of messages, actual character counts were made of the messages broadcast on Monday, September 13, 1976 (radio day 257). A count of the total number of characters contained in each message was made by NAVTELCOM

1/ The test results were $F_{4,857} = 11.68$, and $t = 1.90$ with approximately 53.8 degrees of freedom. The Behrens-Fisher test is intended to test the equivalence of two means when variances are unequal. The form of test used is described in K. A. Brownlee, Statistical Theory and Methodology in Science and Engineering, 2nd edition (New York: John Wiley and Sons, 1965), pp. 299 ff.

using a computer program designed for that purpose. A manual count of the length of the address portion of each message was made for a sample of those messages in order to obtain separate estimates of the lengths of the text and address sections of messages.

We have been advised that radio day 257, 1976 was a normal day in terms of the number and types of messages broadcast to the fleet. The messages for which we obtained character counts ranged from transmissions of weather data to announcements of the next week's movie schedule.

Table III-6 shows, for each of the four broadcast channels, the number of messages transmitted over that channel on radio day 257 (1976), the average length of the messages transmitted (both the address and text sections combined), and the standard deviation of the message length.[1/] Channels A and B are monitored by the Navy's destroyers, Channel D is monitored by the amphibious fleet, and Channel C is monitored by all deployed ships.

1/ The reader will notice that the standard deviations in Table III-6 are much larger than those tabulated in Table III-5, although the means are similar. This is because of the different sources used for the tables. The data in Table III-5 are averages across days, for a given type of channel. Thus, the standard deviations show the variation in message length across days.

On the other hand, the data in Table III-6 are for individual messages on a single day and a single channel. They indicate a much greater variation, as is to be expected since the daily values used in Table III-5 are already averages. The individual data indicate that message lengths are approximately exponentially distributed; something which has been found in many other studies of communications traffic.

Ideally, the hypothesis tests described above for pooling across channels should have been conducted with individual observations. However, we were unable to obtain data on the lengths of individual messages for terminations, and so have relied on the daily average data summarized in Table III-5.

Table III-6

Average Message Length

Broadcast Channel	No. of Observations	Mean Length	Standard Deviation
A	306	1634	2368
B	93	1363	1655
C	387	1814	2081
D	229	1127	1203

A total of 1015 messages were transmitted over the four broadcast channels on the day in question. These messages average a total of 1563 characters (including invisible characters), with a pooled standard deviation of 1980 characters.

The average number of (visible) characters contained in the address section of the sampled messages is shown in Table III-7. Taken together, these 114 messages average an address section length of 213 visible characters. Adding an estimated 37 invisible characters to this figure, we obtain 250 for the approximate total number of characters contained in the address section of the messages sampled. We can then estimate the total number of characters in the text portion of a message to be 1313.

Table III-7

Average Address List Length

Broadcast Channel	No. of Observations	Mean Length	Standard Deviation
A	15	243	382
B	32	155	110
C	25	434	378
D	42	114	149

The data in Tables III-5 through III-7 allow us to estimate the lengths of send and receive messages separately. It is also useful to know the length of an "average" message -- that is, a weighted average over all ships for both send and receive. This information can be obtained from another section of the NAVTELCOM monthly reports, which summarizes worldwide message traffic volumes. Since it is tabulated at the NAVCOMPARS stations the data automatically weight send and receive traffic correctly. For the eight months from January to August, 1977, the average message length is 1185 characters, or roughly 200 words. Also of interest is the character receive/send ratio, which is 2.30 with a standard deviation of 0.156.

D. Broadcast Messages

We examined a sample of broadcast messages provided by NAVTELCOM for two purposes. First, we wished to confirm our estimates of daily message volumes for small ships by comparing them with a count of specifically addressed messages in the broadcast. Second, we wished to see how many messages were required merely to coordinate the broadcast channel, since many of these will be eliminated in an automated system.

1. Overall Analysis

Messages intended for the broadcast may use either the common channel or a channel monitored only by certain types of ship. At Norfolk the common channel is C, while destroyers and frigates also monitor channel A, and auxiliary vessels and amphibious warfare ships monitor channel D. On the day for which we had data, destroyers were also monitoring an overload channel designated as B.

Table III-8 shows the number of messages sent over each of the four broadcast channels (A, B, C and D) to each of ten classes of addressee. Out of a total of 1,536 messages, 772 (50 percent of total) were sent to "collective" addressees such as ALLNAV, ALLSHIPS, to the commanders of task forces, 1/ or to "address indicator groups" (AIG's). We were unable to determine from the printout, however, how many of these messages were repeated on more than one broadcast channel. Overall, destroyers and frigates should have received 1,258 messages on channels A, B and C; while auxiliaries received 951 on channels C and D.

1/ We use the term "task force" here to include numbered fleet commands, task forces, task groups and task units.

Table III-8

Number of Messages Sent to Addressees
of Norfolk Broadcast During 24-Hour Period

	Broadcast Channel				
	A	B	C	D	Total
Collectives(ALLSHIPS, etc.)	31	12	247	23	313
TF Commanders	51	15	134	41	241
AIG's	21	3	50	44	118
CG	13	3	0	0	16
DD	191	54	8	0	253
FF	140	40	1	0	181
MS	0	0	40	0	40
AD	0	0	0	18	18
Other Auxiliaries	1	3	144	40	188
LPD, LPH	0	0	39	40	79
Amphibious Warfare	0	0	4	69	73
Msg. incomplete, or unclassified	7	0	6	3	16
Total	455	130	673	278	1,536

Individual ships addressed in the broadcast traffic were grouped into several classes for analysis. The message counts for these classes are shown in Table III-8, while Table III-9 shows the number of ships in each class addressed over each broadcast channel. Notice that the final column of Table III-9 shows the total number of ships addressed over all

channels, with duplications eliminated. Overall, 64 individual ships were addressed during the day, and may thus be assumed to be copying the Norfolk broadcast.

Table III-9

Classes of Ships Messages Addressed by Name in Norfolk Broadcast

Class	Broadcast Channel				Combined Total 1/
	A	B	C	D	
CG	1	1	0	0	1
DD	13	14	1	0	15
FF	12	9	1	0	13
MS	0	0	7	0	7
AD	0	0	0	1	1
Other "A's"	1	1	10	4	12
LPD, LPH	0	0	2	4	5
Other "L's"	0	0	2	8	9
Total	27	25	23	17	64

1/ Duplications eliminated.

Since each ship will receive all broadcast messages when the 2400 baud channel supported by NAVMACS is in operation, it is necessary to determine the total number of messages received over this link as well as the number of messages actually addressed to the ship. Table III-10 shows summary statistics for the current broadcast, derived from the NAVTELCOM monthly reports. As can be seen from the table, the average load is about 1000 messages, and the average in the MED (which has the highest volume) is about 1300 messages per day, with a monthly peak day averaging 2000 messages. Since we cannot tell in advance where a ship will be assigned, these figures are the appropriate ones that are used for projections.

Table III-10

Broadcast Message Volumes
(January-August, 1976)

	Average Daily Volume	Average Peak Day of Month
LANT	1114	1914
MED	1328	1951
WESTPAC	702	1216
EASTPAC	768	1331
AVERAGE	978	1603

2. Messages Specifically Addressed to Ships

Using Tables III-8 and III-9, Table III-10 shows the number of messages per ship for the individual addresses (i.e., excluding collectives,

command messages and AIG's). The combined column in the table, which gives the average number of individually addressed messages per ship over all broadcast channels, measures the traffic load due to these messages at the receiving ships. As can be seen from the table, this load is surprisingly uniform across ship classes. With the exception of minesweepers and small amphibious warfare ships, all vessels have an average of 13 to 18 messages addressed to them each day. The overall mean is 13.3 messages/day, and the mean excluding minesweepers and small amphibious warfare ships is 15.3.

Table III-11

Average Number of Individually Addressed Messages Per Ship

	A	B	C	D	Combined
CG	13	3	0	0	16
DD	14.7	3.86	8	0	15.8
FF	11.7	4.44	1	0	13.9
MS	0	0	5.71	0	5.71
AD	0	0	0	18	18
Other "A's"	1	3	14.4	10	15.7
LPD, LPH	0	0	19.5	10	15.8
Other "L's"	0	0	2	8.63	8.11
Average	12.8	4.00	10.3	9.8	13.3

These results are in rough agreement with our earlier estimates using data on full-period terminations to small ships. It will be recalled from Table III-2 that FF's were estimated to receive an average of 20.9 messages a day, with a standard deviation of 23.0 messages. The corresponding figures for destroyers are 34.4 and 43.1. Since messages not specifically addressed to the ship also will be routed over the termination, the discrepancy between the two estimates is small, especially in light of the estimated standard deviations.

Some additional part of the difference between broadcast message volumes and volumes measured via terminations can be explained by messages addressed to unit commanders (with addresses of COMDESRON22, and CTU138, for example). Table III-12 shows the number of these messages, and also the number of individually identifiable commanders addressed. 1/ As can be seen from the table, another five to ten messages per day reach unit commanders via the broadcast.

Table III-12

Analysis of Messages Addressed to Commands

	Channel				
	A	B	C	D	Combined
No. of Message	51	15	134	41	241
No. of Commands	7	4	22	5	27
Messages/Command	7.29	3.75	6.09	8.20	8.93

1/ Obvious misspellings of the addressee's identifier (e.g., COMDESRONZZ) were not counted in preparing this table.

3. Communications Overhead

The collective addressee messages tabulated in Table III-8 include messages from the shore station to ship's communication centers intended to coordinate the broadcast. Most of these are RECAPS, which summarize the messages sent during a recent period. A few are services, which are retransmissions of a garbled or missed message at the request of one of the ships monitoring the broadcast.

Table III-13 breaks down collective addressee messages so as to isolate these overhead messages. As shown in the table, 109 messages are RECAPS or services, equal to 7.1 percent (109/1536) of all messages tabulated.

Table III-13

Content of Collective Addressee Messages

Content	Broadcast Channel				Total
	A	B	C	D	
Environmental	1	1	123	2	127
Communications RECAPS and Service Requests	22	3	63	21	109
Other Communications	3	4	15	0	22
All Other	5	4	46	0	55
Total	31	12	247	23	313
Total (excluding RECAPS and Service Requests)	9	9	184	2	204

E. Traffic Estimates

We are now in a position to calculate overall traffic volumes for the eleven ship classes defined in Section B. Using the message length statistics calculated in Section C, we calculate estimates of the daily average number of characters sent to and received by each ship class. The results of this calculation are given in Table III-14, which also shows the average combined volume of characters, and the estimated ratio of characters received per character sent. 1/ As can be seen from the table, receive/send ratios of ten to twenty-five appear typical for the all but the lowest volume ships. The fact that shore-ship messages are longer than ship-shore messages accentuates the difference in send/receive character volume, compared to the message volumes shown in Table III-2. The larger CG's have the highest volume, at 670 thousand characters per day. CV's and AD's also have high character rates (470 and 317 thousand respectively).

Unfortunately, it is not possible to calculate estimates of the 90th percentile of the character rate distribution directly, because such an estimate would require a knowledge of the distributions of both message volume and message length.

1/ In calculating the ratio, the correlation between messages sent and received was taken into account. The resulting estimate is unbiased, but will not exactly equal the ratio of the character rates shown in Table III-14.

Table III-14

Estimated Daily Character Loads
(thousands of characters, including headers)

	Average Received	Average Sent	Average Combined	Characters Received Per Character Sent
Combatants				
CV, CVN	422	48.1	470	8.79
Larger CG, CGN	640	29.3	670	21.9
Smaller CG, CGN	126	13.6	140	10.8
DD, DDG	51.6	9.49	61.1	5.46
FF, FFG	31.3	9.50	40.8	3.31
Amphibious Warfare Ships				
LCC, LHA, LPD, LPH	205	19.7	224	10.4
Other (LKA, LSD, LST, etc.)	46.2	7.67	53.9	6.07
Auxiliaries				
AD	306	11.2	317	27.3
AFS	131	14.2	146	9.36
AS	179	9.96	189	17.9
Other (AE, AO, AOE, etc.)	96.2	8.31	105	11.5

Table III-14 summarizes our knowledge of the character traffic load which an automated message processing facility is subjected during routine operations. Similarly, Table III-3 summarizes the message load. These data can be used to project message processing loads for future routine operations, and also under crisis conditions. These projections will be the subject of Chapter IV.

However, we can draw some conclusions without making projections. One striking feature is the important contribution to overall volumes made by command traffic or traffic involving ships with a command capability. For example, if ships with a major command capability (CV's, larger CG's, LCC, LHA, LPD, LPH, AD and AS) are considered separately from all other ships, one finds the pattern shown in Table III-15. The seventy-odd ships with command capability send and receive four times as many messages, and more than four times as many characters, during an average day under routine conditions, compared to the remaining ships in the Navy. Moreover,

Table III-15

Effect of Command Capability in Message Traffic Loads

	Approx. No. of Ships	Average Daily Message Traffic	Average Daily Characters (thousands)
Ships with Command Capability	70	259	338
All Other Ships	345	64	75
Total	415	97	119

as shown in Table III-16, the distribution of daily messages is different for these two groups; ships with command capability exhibit a bi-model distribution, while the other ships do not.

Another feature of the data can be seen by looking separately at combatants, amphibious warfare ships and auxiliary vessels. This is done in Table III-17. As can be seen from the table, the auxiliaries have the highest overall average traffic levels, measured either in messages or characters. While not the most numerous type of ship, they contribute 37% of all traffic (measured in characters). This contribution results from the fact that most combatants are destroyers or frigates, which have low traffic rates compared to the smaller logistic ships (AE, AOE, AO and so forth).

These two observations, as well as some others made during the course of this chapter, emphasize an important point: message communications traffic volumes are heavily dependent on the functions or activities performed aboard ship. To the extent that different classes of ship perform the same function, these classes may be regarded as similar from the point of view of communications. Moreover, whenever the functions performed are changed, we should expect communications patterns to change as well.

While a detailed examination of the functional basis of communications is beyond the scope of this analysis, such an analysis, if it were conducted, would reveal these patterns more clearly. While the patterns so revealed would doubtless differ in detail from the ones mentioned here, we believe the current work has developed the main outlines sufficiently for later use. Thus, the next step in our analysis is to use the data presented here to project message traffic loads in the future, and in crisis situations.

Table III-16

Effect of Command Capability on Distribution of Message Traffic

Average Daily Messages	Percent of Time, All Ships	Percent of Time, Ships w/ Command Capabilities	Percent of Time, All Other Ships
0-50	51	24	58
50-100	24	15	26
100-200	13	19	12
200-300	6	26	2
300 +	6	16	2
Total	100	100	100

Table III-17

Average Message Traffic by Type of Ship

	Approx. No. of Ships	Average Daily Messages	Average Daily Characters (thousands)	Share of Total Characters (present)
Combatants	215	94.5	112	48.6
Amphibious Warfare Ships	70	85.1	103	14.5
Logistics Ships	130	106.7	140	36.8

CHAPTER IV

PROJECTIONS OF MESSAGE TRAFFIC USING NAVMACS

This chapter continues the analysis conducted in the preceeding chapter. Using the data presented there, and a model of the message generating process, we predict (1) peak message and character loads under routine conditions, and (2) message and character loads under crisis conditions, for our eleven aggregate ship classes when equipped with a NAVMACS configuration.

The process of predicting peak loads has been undertaken in several steps. First, we ask what the data presented in the last chapter can tell us about peak loads at present. Using a model of the day-to-day variation in traffic aboard a ship, we develop estimates for 30 day and 365 day peak loads, assuming routine conditions and 1976 traffic volumes. Next, using data on the Frequent Wind and Mayaguez operations, we develop estimates of message volume when crisis conditions superimpose an additional load on a 30 day peak. Finally, we adjust our estimates for both routine and crisis level traffic to account for changing communications conditions between the present and the 1980's, when most ships in the Navy should be equipped with NAVMACS.

Because NAVMACS processes messages both addressed to it and not addressed to it, we have carried out the steps outlined above several times: for each aggregate ship class, for the new 2400 baud broadcast, and for CUDIXS. Once we have all these estimates, we are able to develop estimates for the traffic that will have to be handled by a NAVMACS. These

estimates are presented at the end of the chapter.

A. Development of a Model for Predicting Peak Loads

Our approach to prediction, described in more detail below, is to fit a probability distribution to the data, and use this distribution to predict the peak loads. We have taken this approach because of some difficulties associated with using the data in more usual modeling approaches.

1. Factors Causing Variation in the Traffic Data

As discussed in the preceeding chapter, there is still significant variation in message volumes within classes after defining the eleven ship classes. Sources of this variation may include:

- Deterministic factors, such as:
  - Monthly or quarterly cycles,
  - Differences due to location (LANT vs. MED, for example),
  - Differences in operational assignment (e.g., whether or not a carrier has an air group embarked).
- Random factors, such as:
  - Differences in communications center procedures,
  - Differences in message volumes due to differences in personnel, crew size, etc.

In principle, the deterministic factors should be treated separately from the random ones. For instance, monthly or quarterly cycles should

be identified by averaging message volumes over many years of data, and the overall averages adjusted accordingly. Unfortunately, the monthly report data used does not permit this sort of adjustment, either for cyclical variation or for the other deterministic factors listed above.

Because we do not adjust for deterministic factors, the calculated standard deviations in Tables III-2 and III-3 above overstate the influence of the random factors, as was discussed in the preceding chapter. As can be seen from these tables, the standard deviations are all about the same size as the averages. This was an unexpected finding, since if the ships within an aggregated class were truly homogeneous we would expect a Poisson model to apply. In this case the standard deviation would be equal to the square root of the average. 1/

Another approach to estimating peak volumes would be to use NAVCOMPARS data as a proxy for the shipboard data. However, since each NAVCOMPARS serves many ships its daily volume is averaged over many ships. As a consequence, NAVCOMPARS peaks will be relatively closer to the average than a single ship's peak. 2/ For example,

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1/ The Poisson model, discussed below, is frequently used in communications when messages or other events occur completely at random over time.

2/ The reason why peaks are understated is that, because of the law of large numbers, the standard deviation of the average is reduced compared to the standard deviation of individual values. However, the average of NAVMACS experience is still an unbiased estimator of the average experience on a ship.

the monthly report data show that the ratio of peak day to average day volume over one month periods at a NAVCOMPARS is about 1.4 for terminations. [1] As we will see below, the predicted 30 day peak-to-average ratio for an individual ship is almost three.

We are thus faced with a dilemma: data on individual ships has too much variation because we cannot adjust for deterministic differences, while data from NAVCOMPARS sites has too little variation. We have resolved this dilemma by building a model of the overall message generating process, as described in the next section.

2. Mixed Poisson Model

As noted above, the eleven ship classes do not, for a variety of reasons, constitute homogeneous sources of messages. If they were homogeneous, it would be natural to model them by standard Poisson theory, [2] which gives the probability of sending or receiving n messages in a day to be:

$$p(n|a) = \frac{a^n e^{-a}}{n!}$$

where $n = 0, 1, 2, \ldots$ and a is a parameter. The average and standard deviation of n are a and $\sqrt{a}$, respectively.

1/ During the period January-August 1976, the ratio was 1.429 for ship-shore terminations with the largest value actually observed being 1.88. For shore-ship terminations the ratio averaged 1.426, with the largest value being 1.75.

2/ There are any number of excellent discussions of the Poisson process, and its role in communications as well as other fields. See, for example, W. Davenport, Probability and Random Processes (New York: McGraw Hill, 1970), Chapter 13.

Because we are dealing with heterogeneous classes, the value of a will vary within any class. Some of this variation is due to deterministic factors, and some to random factors. In any case, we do not have the data to identify and adjust for these influences. Lacking detailed knowledge of the cause of variation in the parameter a, we will treat it as a random variable with its own probability distribution.[1/] A particularly convenient distribution to use in this case is the gamma distribution:

$$f(a \mid \alpha, r) = \frac{(\alpha a)^{r-1} e^{-\alpha a} \alpha}{\Gamma(r)}$$

where α and r are parameters. In terms of the parameters, the average and standard deviation of the Poisson parameter a are r/α and $\sqrt{r}/\alpha$.

Since a is unknown, we integrate it out and get the probability of n messages given the parameters α and r:

$$p(n \mid \alpha, r) = \int_0^\infty p(n|a) f(a|\alpha, r)\, da$$

$$= \int_0^\infty \frac{a^n e^{-a} (\alpha a)^{r-1} e^{-\alpha a}}{n!\,\Gamma(r)} \alpha da$$

$$= \frac{\alpha^r}{\Gamma(r) n!} \int_0^\infty a^{n+r-1} e^{-(1+\alpha)a} da$$

$$= \frac{\alpha^r}{\Gamma(r) n!} \frac{\Gamma(n+r)}{(1+\alpha)^{n+r}}$$

$$= \frac{\Gamma(n+r)}{\Gamma(r) n!} p^r (1-p)^n$$

1/ This approach was originated by M. Greenwood and G. Yule in 1920. See Kendall and Stuart, The Advanced Theory of Statistics, Vol. 1, 4th edition (New York: MacMillan, 1977) p. 136 ff.

where $p = \alpha/(1+\alpha)$. The distribution $p(n|\alpha, r)$ is called the negative binomial distribution. The average and standard deviation of n are r/α and $\sqrt{r(1+\alpha)}/\alpha$, respectively. This distribution is a mixture of Poisson distributions, where the mixture is governed by the gamma distribution. The important thing about the negative binomial distribution, from our point of view, is that the standard deviation of n can be much larger than implied by the Poisson.

B. Tests of Fit for the Negative Binomial Distribution

Since the average and standard deviation of the negative binomial involve two parameters, it is possible to fit our empirical distributions (displayed as histograms in the previous chapter) to the negative binomial distribution. If the fit is satisfactory we can use the negative binomial distribution to project peak loads.

This was done for each of the eleven aggregated ship classes. The parameters α and r (equivalently, p and r) were estimated using the averages and standard deviations shown in Table III-3. The negative binomial distribution was then calculated at the same intervals as the histograms tabulated in the previous working paper, and a Chi-squared test performed. The hypothesis being tested was that the observed histogram was generated by a negative binomial distribution with the average and standard deviation tabulated in Table III-3. The results of this test are given in Table IV-1. 1/ As

1/ Here, as throughout this chapter, we have deleted the three observations on an AR which were assigned to the "other auxiliaries" class in the preceeding chapter. This ship was flying a major flag at the time, and is not typical of the rest of the group. If these observations are not deleted, the test of fit gives $\chi^2_5 = 19.88$, with an associated probability level of 1.32×10^{-3}.

Table IV-1

Results of Tests of Fit by Class of Ship

Ship Class	No. of Degrees of Freedom	Value of χ^2	Probability Level
Combatants			
Carriers (CVA, CV, CVN, CVT)	9	10.02	.349
Larger Cruisers (CG & CGN)	6	61.90	$\sim 7 \times 10^{-10}$
Smaller Cruisers (CG & CGN)	3	.765	.858
Destroyers (DD & DDG)	6	6.14	.408
Frigates (FF & FFG)	5	7.76	.170
Amphibious Warfare Ships			
LCC, LHA, LPH & LPD	9	15.26	.084
Other (LKA, LSD, LST, etc.)	4	3.83	.430
Auxiliaries			
Destroyer Tenders (AD)	4	7.05	.133
Combat Stores Ships (AFS)	3	3.32	.345
Submarine Tenders (AS)	2	11.28	3.5×10^{-3}
Other (AE, AO, AOE, etc.) 1/	5	6.76	.239

1/ Excluding one AR.

AD-A049 940 MATHEMATICA INC PRINCETON N J MATHTECH DIV F/G 17/2
A COST EFFECTIVENESS ANALYSIS OF THE NAVAL MODULAR AUTOMATED CO--ETC(U)
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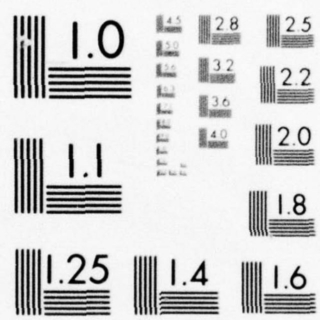

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

can be seen from Column 3 of the table, the probability levels are such that we cannot reject the hypothesis (except in two cases) at the 0.005 level. [1]

These test results are fairly convincing in themselves, especially because the two exceptions (larger CG's and AS's) can be explained fairly readily. In both cases, the empirical distribution of traffic volumes is bimodal, reflecting the fact that these ships either generate lots of traffic or very little. In the case of larger CG's, this is probably due to the presence or absence of a major flag on board ship. In the case of AS's, it is probably due to the fact that the tender may process messages for submarines tied up along side, so that the larger of the two peaks in traffic is generated by two or three vessels instead of only one.

Indeed, these two exceptions help to confirm the original idea that we were observing a mixture of Poisson processes. If we truncate the empirical distributions for these two classes, we can recalculate some of the means and standard deviations of daily messages:

- For large CG's with daily messages over 400, the mean is 778 with a standard deviation of 43.8, and
- For AS's with daily messages over 150, the mean is 292 with a standard deviation of 34.4.

1/ The probability level shown in the table is the probability of getting a value of χ^2 larger than the value shown in Column 2, given that the distribution is the negative binomial used in the test.

Even this simple partitioning results in sharp reductions in the standard deviation.

A second test of the negative binomial model was also conducted to see how well the theoretical distributions predicted the ninetieth percentile of the empirical distributions. While no hard statistical interpretation can be placed on the test results, they do give some indication of the accuracy of predictions of extreme values using the negative binomial. This is an important point to consider, since we will predict extreme values in the next section.

Table IV-2 shows the results of this test. The first column gives the value of the shape parameter (r) of the negative binomial while the second column shows the predicted ninetieth percentile. The observed percentile (reproduced from Table III-3) is shown in the third column, while the fourth column presents the relative difference between the predicted and observed values.

As can be seen from the fourth column, the agreement is relatively good -- the average absolute error is 8.0 percent. Even the two classes which failed the Chi-squared test appear to be represented fairly well by the negative binomial distribution in their tails. [1] As a result, we

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1/ This is not completely accidental. When the number of daily messages is large, it can be shown that the negative binomial approaches a Gamma distribution which, like the Normal distribution, has the property that its right tail decreases exponentially. The limiting result is mentioned in H. Raiffa and R. Schlaiffer, Applied Statistical Decision Theory, (Cambridge, Massachusetts: MIT Press, 1968) p. 286. The exponential property is discussed in E. Gumbel, Statistics of Extremes, (New York: Columbia University Press, 1958) pp. 122-49.

Table IV-2

Comparison of Estimates of Ninetieth Percentile

Ship Class	Estimated Shape Parameter (r)	Estimated Ninetieth Percentile	Observed Ninetieth Percentile	Percent Difference
Combatants				
Carriers (CVA, CV, CVN, CVT)	1.93	757	814	-7.0
Larger Cruisers (CG & CGN)	2.18	935	865	8.1
Smaller Cruisers (CG & CGN)	.890	269	265	1.5
Destroyers (DD & DDG)	.971	128	133	-4.0
Frigates (FF & FFG)	1.86	82.2	88	-6.6
Amphibious Warfare Ships				
LCC, LHA, LPH & LPD	1.47	375	405	-7.4
Other (LKA, LSD, LST, etc.)	1.37	101	91	11.1
Auxiliaries				
Destroyer Tenders (AD)	2.89	408	500	-18.3
Combat Stores Ships (AFS)	2.89	212	199	6.5
Submarine Tenders (AS)	1.55	291	273	6.6
Other (AE, AO, AOE, etc.) 1/	.970	141	159	-11.4

1. Excluding one AR.

have continued to use the negative binomial distribution for these two classes of ship in making our projections of traffic volume. If anything, retaining these distributions will cause an over-estimate of the traffic, because the much smaller standard deviations discussed above make the extreme levels with which we are concerned less likely rather than more likely.

C. Predictions of Message Loads for 1976 Conditions

In order to predict the message loads under routine and crisis conditions, we use the negative binomial distributions evaluated in the preceeding section. Our basic approach is to calculate the level of

traffic which is exceeded, on average, once in some specified time period. The time period is usually called the "return period" or "renewal interval," and the associated traffic level the "critical value."

The rationale for this approach is as follows. If x is some particular message volume, then $P(x)$ is the probability that message volume on a given day is less than or equal to x. (In our case, we calculate $P(x)$ from the formula for the negative binomial.) It follows that $1 - P(x)$ is the probability that message volume exceeds x on a given day. If the same probability distribution holds on successive days, then the probability that t days elapse between "exceedances" of x is $[1 - P(x)]P(x)^{t-1}$, since $(t-1)$ days with traffic less than x must preceed the day when the traffic exceeds x. The average time between exceedances (i.e., the average value of t) can be shown to be:

$$T(x) = \frac{1}{1 - P(x)} \quad 1/$$

---

1. This result can be shown as follows:

$$T(x) = \sum_{t=1}^{\infty} [1 - P(x)]\, tP(x)^{t-1}$$

$$= [1 - P(x)] \sum_{t=1}^{\infty} \sum_{k=1}^{t} P(x)^{t-1}$$

$$= [1 - P(x)] \sum_{k=1}^{\infty} \sum_{t=k}^{\infty} P(x)^{t-1}$$

$$= [1 - P(x)] \sum_{k=1}^{\infty} P(x)^{k-1} \cdot \sum_{n=0}^{\infty} P(x)^{n} \quad \text{(where } n=t-k\text{)}$$

$$= \sum_{k=1}^{\infty} P(x)^{k-1}$$

$$= \frac{1}{1 - P(x)}$$

Notice that this time becomes larger and larger as P(x) approaches one, so that very large volumes are relatively rare events.

Since we know the function P(x), we can obviously find T(x) also. In estimating peak volumes, we have specified values of the average return period T(x) (7 days, 30 days, 365 days and so on), and solved numerically for the corresponding critical value of x.[1/]

1. Peak Traffic for Aggregate Ship Classes Under Routine Conditions

Table IV-3 shows our results for the eleven ship classes. Column one reproduces the average traffic levels shown in Table III-3, while columns two and three show the critical traffic levels associated with 30 day and 365 day return periods. The fourth column shows the ratio of the 30 day critical value to the average, indicating the "multiplier" on average traffic that is appropriate to each class. For the 30 day peaks, the median value of the multiplier is 2.87, while the mean is 2.89. For the 365 day peaks, the median and average multipliers (not shown separately in the table) are 4.38 and 4.55, respectively.

1/ Thus, if we let $T(x) = 30$ days, we find the value of x such that $P(x) = 1 - 1/30 = 0.96667$. For the negative binomial, x is an integer and a search algorithm was employed to find the smallest value of x such that $P(x) \geq 1 - 1/T(x)$.

Table IV-3

Predicted Peak Message Loads Under Routine Conditions

Ship Class	Average Daily Messages	Predicted 30 Day Peak	Predicted 365 Day Peak	Ratio of 30 Day Peak to Average
Combatants				
Carriers (CVA, CV, CVN, CVT)	386	1020	1520	2.64
Larger Cruisers (CG & CGN)	491	1240	1820	2.53
Smaller Cruisers (CG & CGN)	114	405	673	3.55
Destroyers (DD & DDG)	55.1	189	310	3.43
Frigates (FF & FFG)	41.5	111	165	2.67
Amphibious Warfare Ships				
LCC, LHA, LPH & LPD	179	523	806	2.92
Other (LKA, LSD, LST, etc.)	47.5	142	221	2.99
Auxiliaries				
Destroyer Tenders (AD)	228	527	741	2.31
Combat Stores Ships (AFS)	118	273	384	2.31
Submarine Tenders (AS)	141	404	617	2.87
Other (AE, AO, AOE, etc.) 1/	60.7	209	343	3.44

1. Excluding one AR.

We can also use the negative binomial distribution to predict peak loads for send and receive traffic separately. In doing this, we have to assume that send and receive volumes are independent -- which we know

is untrue from the previous chapter -- because we do not know enough to specify the joint distribution. 1/ These predictions are shown in Table IV-4. However, since we do not have separate histograms for send and receive traffic we cannot place the same degree of confidence in these estimates as we can in the estimates in Table IV-3.

Table IV-4

Predicted Peak Message Volumes

Under Routine Conditions

Ship Class	Receive		Send	
	Predicted 30 Day Peak	Predicted 365 Day Peak	Predicted 30 Day Peak	Predicted 365 Day Peak
Combatants				
Carriers (CVA, CV, CVN, CVT)	757	1180	286	450
Large Cruisers (CG, CGN)	1120	1740	149	220
Smaller Cruisers (CG, CGN)	343	646	89	146
Destroyers (DD & DDG)	141	265	68	116
Frigates (FF, FFG)	77	137	56	89
Amphibious Warfare Ships				
LCC, LHA, LPH, & LPD	419	696	124	201
Other (LKA, LSD, LST, etc.)	101	173	53	88
Auxiliaries				
Destroyed Tenders (AD)	491	735	46	62
Combat Stores Ships (AFS)	236	369	52	67
Submarine Tenders (AS)	350	569	57	88
Other (AE, AO, AOE, etc.) (excluding AR)	182	355	46	75

1/ As a consequence, the predicted peak volumes will not add up to the combined volume.

2. Traffic Under Crisis Conditions for Aggregate Ship Ship Classes

To arrive at crisis estimates we will superimpose an additional traffic load on a "background" level of traffic. While the 365 day peak could be used for this background if a truly worst case analysis were sought, we believe that the 30 day peak more realistically represents the amount of background traffic that will be encountered in crisis operations. We have therefore used the 30 day peak value in our calculation of crisis traffic loads.

The amount of traffic due to a crisis itself (i.e., excluding the background) is a hard number to quantify. Perhaps the best data in this case come from NAVTELCOM, which draws on experience in the Mayaguez and Frequent Wind operations. The data indicate that traffic through the Guam NAVCOMPARS increased by 50 percent during these operations. 1/

In addition, NAVTELCOM reports an increase in the transmit-to-receive ratio of messages during a crisis. This ratio measures the number of different destinations to which a message was sent. During Frequent Wind and Mayaguez, the transmit-to-receive ratio increased from a normal 1.8 to 2.0, or roughly 11 percent. When combined with the 50 percent traffic increase, the overall increase at the NAVCOMPARS in messages transmitted was 67 percent (1.67 = 1.50 x 1.11).

1/ The actual changes were to 6,100 and 6,300 messages per day, from a base of 4,000. However, some of this increase is attributed by NAVTELCOM to a quarterly peak in traffic such as we have tried to account for by using a mixed Poisson model. Hence, we use 50 percent for the traffic increase.

This increase, of course, will be reflected in the fleet by a proportional increase in the Poisson parameter. (Since this is equal to the average value, we need not worry about the law of large numbers in making this statement.) Thus, multiplying the 30 day critical traffic volumes by 1.67 gives an estimate of the traffic loads involved under crisis conditions. These estimates are shown in Column one of Table IV-5, and Column two presents the multiplier associated with the crisis estimates. The median multiplier is 4.78 times the average -- roughly a factor of five. Table IV-6 shows similar estimates for send and receive traffic separately.

Table IV-5

Combined Message Loads Under Crisis Conditions

Ship Class	Messages Per Day Under Crisis Condition	Ratio Crisis Message Rate to Daily Average
Combatants		
Carriers (CVA. CV, CVN, CVT)	1700	4.40
Larger Cruisers (CG & CGN)	2070	4.22
Smaller Cruisers (CG & CGN)	675	5.92
Destroyers (DD & DDG)	315	5.72
Frigates (FF & FFG)	185	4.45
Amphibious Warfare Ships		
LCC, LHA, LPH & LPD	872	4.87
Other (LKA, LSD, LST, etc.)	237	4.98
Auxiliaries		
Destroyer Tenders (AD)	878	3.85
Combat Stores Ships (AFS)	455	3.85
Submarine Tenders (AS)	673	4.78
Other (AE, AO, AOE, etc.) 1/	348	5.73

1/ Excludes one AR.

Table IV-6

Send and Receive Message Loads Under Crisis Conditions

Ship Class	Messages Received Under Crisis Conditions	Messages Sent Under Crisis Conditions
Combatants		
Carriers (CVA, CV, CVN, CVT)	1260	477
Larger Cruisers (CG & CGN)	1870	248
Smaller Cluisers (CG & CGN)	572	148
Destroyers (DD & DDG)	235	113
Frigates (FF & FFG)	128	93
Amphibious Warfare Ships		
LCC, LHA, LPH & LPD	698	207
Other (LKA, LSD, LST, etc.)	168	88
Auxiliaries		
Destroyer Tenders (AD)	818	77
Combat Stores Ships (AFS)	393	87
Submarine Tenders (AS)	583	95
Other (AE, AO, AOE, etc.) 1/	303	77

1. Excludes one AR

3. Character Processing Loads

To estimate the character processing loads, we need to know the average message lengths under routine and crisis conditions. Table IV-7 summarizes the data available on message lengths in these two cases. The average length of 1,200 characters under routine conditions corresponds to the length we measured from NAVTELCOM tabulations, as reported in the preceeding chapter.

Table IV-7

Impact of Crisis Conditions on Precedence Distributions and Message Lengths

	Routine Conditions		Crisis Conditions	
Precedence	Message Length (Characters)	Share in Traffic (Percent)	Message Length (Characters)	Share in Traffic (Percent)
Flash	500	2	1300	6
Immediate	1200	20	2000	30
Priority	1200	40	2000	39
Routine	1200	38	1700	25
Combined	1200	100	1900	100

Source: Columns 1 and 3, Rows 2, 3 and 4 derived from E. A. Babineau, "A Statistical Description of 1985 Record Communications Among Navy Platforms and Shore Stations (U)," MITRE Corporation, MTR-4677, March 1976, Confidential.

Columns 2 and 4, and Row 1 of Columns 1 and 3, from OPNAVMemo 04/212 (22 October 1976).

As can be seen from the table, under crisis conditions the proportion of Flash and Immediate precedence messages increases, and the average length of all messages also rises. What may be happening is that some precedences are increased during a crisis, raising average message lengths observed at higher precedence levels. However, there is no hard evidence for this. Also, notice that although the percentage of Routine precedence messages falls during a crisis, the number of Routines is unchanged because the overall volume of traffic rises by 50%. (That is 25% x 1.5 = 38%).

As shown in the table, the overall effect of a crisis is to increase the average length of a message from 1,200 characters to 1,900 characters (about 58 percent). There is no reason to believe that message lengths are longer on peak days under rountine conditions than otherwise. Hence, the predicted character loads for the eleven ship classes are as shown in Table IV-8.

As pointed out in the previous chapter, average message lengths vary for different classes of ship because the send/receive ratios differ. These differences are preserved in Table IV-8 by using (in Column one) the estimates derived in the earlier chapter (Table III-12). These are then increased by (1) the 30-day-to-average message multiplier given in Table IV-3, (2) a multiplier of 1.67 for crisis messages, and (3) a multiplier of 1.58 (=1900/1200) to account for increased message length. This gives the crisis value shown in Column three.

Table IV-8

Predicted Daily Character Loads

(thousands of characters)

Ship Class	Average 2/	Crisis Conditions	Ratio of Crisis To Average
Combatants			
Carriers (CVA, CV, CVN, CVT)	470	3270	6.97
Larger Cruisers (CG & CGN)	670	4470	6.68
Smaller Cruisers (CG & CGN)	140	1310	9.37
Destroyers (DD & DDG)	61.1	553	9.05
Frigates (FF & FFG)	40.8	287	7.05
Amphibious Warfare Ships			
LCC, LHA, LPH & LPD	224	1730	7.71
Other (LKA, LSD, LST, etc.)	53.9	425	7.89
Auxiliaries			
Destroyer Tenders (AD)	317	1930	6.10
Combat Stores Ships (AFS)	146	890	6.10
Submarine Tenders (AS)	189	1430	7.57
Other (AE, AO, AOE, etc.) 1/	72.8	661	9.08

1/ Excluding one AR.

2/ Table III-12.

The table shows that the impact of a crisis, measured in terms of characters, is substantially larger than when measured in terms of messages. The median multiplier for crisis loads, in terms of characters, is 7.57, (roughly 7.5), compared to the message multiplier of 4.8.

4. Comparisons Over Aggregated Classes

As we did in the preceeding chapter, it is interesting to compare the predicted character and message loads over several more aggregated classes. Tables IV-9 and IV-10 show message rates (routine and crisis conditions) for combatants, amphibious warfare ships, and auxiliaries. As pointed out in the previous working paper, the auxiliary ships have the largest average loads under routine conditions. However, under crisis conditions combatants have slightly higher message rates; the relationship changes less for character rates because the message length is slightly shorter.

It is also interesting to contrast the loads for ships with major command capability (CV, CVN, larger CG and CGN, LCC, LPH, LPD, LHA, AS and AD) with the loads for ships lacking this capability. Tables IV-11 and IV-12 show send and receive messages separately. Tables IV-13andIV-14 provide this comparison for all messages. As shown, command capability involves an additional 830 messages per day during a crisis, (roughly 700 more received, and 130 more sent), with a corresponding increased character load of about 1.8 million characters. Command capability involves three to four times the load, under either routine or crisis conditions.

Table IV-9

Combined Daily Message Loads by Type of Ship

Ship Class	Routine Conditions	Crisis Conditions
Combatants	94.5	465
Amphibious Warfare	85.1	418
Auxiliary	107	447
Combined	97	452

Table IV-10

Combined Daily Character Load by Type of Ship

(Thousands of Characters)

Ship Class	Routine Conditions	Crisis Conditions
Combatants	112	867
Amphibious Warfare	103	798
Auxiliary	140	897
Combined	119	864

Table IV-11

Effect of Command Capability on Daily Message Loads

(Receive Only)

Ship Class	Routine Conditions	Crisis Conditions
Ships With Command Capability	210	949
All Other Ships	44	247
All Ships	72	365

Table IV-12

Effect of Command Capability on Daily Message Loads

(Send Only)

Ship Class	Routine Conditions	Crisis Conditions
Ships With Command Capability	50	217
All Other Ships	20	97
All Ships	25	117

Table IV-13

Effect of Command Capability on Combined Daily Message Loads

Ship Class	Routine Conditions	Crisis Conditions
Ships With Command Capability	259	1140
Other Ships	64	312
Difference	195	828

Table IV-14

Effect of Command Capability on Combined Daily Character Load

(Thousands of Characters)

Ship Class	Routine Conditions	Crisis Conditions
Ships With Command Capability	338	2340
All Other Ships	75	565
Difference	253	1775

5. Predictions of Broadcast and CUDIXS Volumes

It is also necessary to predict broadcast message loads under crisis conditions, since all messages sent over the broadcast must be processed by NAVMACS. Our analysis of current broadcast messages (Section III. D. 1) indicated that the average daily volume for January-August 1976 was 1300 messages, with an average monthly peak of about 2000 messages. Applying our expansion factor 1.67 to the monthly peak provides us with an estimate of broadcast message volume during crisis conditions. Using this factor, plus an allowance for an increase in message length to 1900 characters, gives character volume estimates. These predictions are shown in Table IV-15.

Table IV-15

Predicted Broadcast Traffic Loads

Condition	Messages/Day	Million Characters/Day
Average, routine operations	1300	2.0
Average monthly peak, routine operations	2000	3.0
Crisis	3300	6.3

We also may use the data in Tables IV-9 and IV-12 to estimate the approximate loads that will be placed on the CUDIXS satellite channel. As discussed in Chapter II, CUDIXS operates on two modes. One allows up to sixty ships to send messages, while the other allows up to ten ships to have two-way communications while up to fifty ships continue in a send-only mode.

Based on our analysis of message lengths and send/receive volumes, it is clear that the second mode of operation produces the most volume, because more messages are received than are sent, and because these messages are longer. Assuming the mix of ships using the channel is the same as the overall mix of ships in the Navy, the totals in Tables IV-9 and IV-12 above then provide estimates of the contribution of each ship on the network to total traffic. Based on this estimate, Column 4 of Table IV-16 shows the number of messages daily transmitted over a CUDIXS net, for the number of ships and conditions given in Columns 1 through 3. As expected, the worst case occurs with 10 ships in a two-way communications, and fifty ships in send-only communications, under crisis conditions. In this case the CUDIXS net will have to handle approximately 10,000 messages per day.

It is also possible to estimate the number of message characters (i.e., characters excluding CUDIXS overhead) that a CUDIXS net will be called upon to handle. Our estimates are shown in Column 4 of Table IV-16. In making them, we have used the message length data for send-only messages described in Section III. E. Under crisis conditions, we have assumed that message lengths rise from 460 characters to 750 characters, a factor in proportion to the 1900/1200 increase for all messages. As can be seen from the table, in the worst case CUDIXS will be called on to pass roughly 13 million characters per day.

Table IV-16

Representative CUDIXS Traffic Volume

No. of Ships Send Only	Two-Way	Condition	Messages/Day	Millions of Characters/Day
30	0	Routine	750	.35
25	5	Routine	1110	.87
50	10	Routine	2220	1.7
60	0	Crisis	7020	5.3
25	5	Crisis	5185	6.5
50	10	Crisis	10370	13.0

D. Predictions of Traffic Loads for the 1980's

Thus far in this chapter, we have concentrated on predicting message traffic from the data analyzed in Chapter III. This has meant that we were, in effect, predicting loads on the basis of 1976 traffic. However, NAVMACS will really operate in the 1980's. Therefore, in this section we adjust our predictions to account for changes in the pattern and volume of Naval messages over the next decade. As discussed below, we have almost no data on which to base our projections. Our basic approach is therefore to assume that command-related traffic will grow under routine conditions by a given factor, and then to repeat the calculations of crises loads made in the last section, beginning with this higher baseline.

1. Growth Rates and Inflation Factors

The usual procedure in projecting traffic growth assumes an overall increase in traffic to all ships. However, there is seldom much justification provided for the use of any specific growth rate--phrases

such as "accounts for the continuing growth of the Navy's message traffic," are often all that appear. Sometimes, an appeal is made to the rate of growth of Gross National Product (GNP) or some other time series, and the historical growth rate of that aggregate is used. This approach may appear plausible, but the results can be nonsensical. For example, using GNP as a predictor of message traffic implies that the Navy's communication volume falls during recessions.

The problems with simple extrapolations are obvious. At best, one is taking a correlation to be a causal relation. At worst, one is merely justifying an ad hoc selection of some factor. Even relatively hard data should not be extrapolated blindly. For example, NAVTELCOM reports indicate that NAVCOMPARS "receive" traffic is growing at a compound annual rate of 8.9%.[1/] This implies that total NAVCOMPARS traffic doubles about every eight years. But, although no precise figures are available, current NAVCOMPARS configurations have less than a factor of two in spare capacity remaining. Thus, if this growth rate continues the shore component of the Navy's communication system will saturate around 1985--something that is not expected to occur. And, there is no point in assuming that NAVMACS will handle more traffic than the NAVCOMPARS sends.

As the evidence presented in these two chapters suggests, however, there are meaningful determinants of traffic volume. In particular,

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1/ Specifically, the following data were supplied at our request:

Period	Message Volume
Jan-Jun '75	3,079,474 (Corrected for Frequent Wind & Mayaguez)
Jan-Jun '76	3,276,857
Jan-Jun '77	3,681,474

changes in the functions (especially command and control) carried out aboard ship can be expected to produce changes in traffic volumes. Given data on ships in commission, personnel, number of task groups and other information, it should be possible to build a model that gives useful predictions.

Unfortunately, such an effort is beyond the scope of this analysis. Thus, we cannot improve greatly on the approaches which we criticized a few paragraphs back. However, based on our present knowledge of Navy communications, we feel that some qualitative statements about the nature of growth can be made.

First, as noted above, the command and control function appears to have a major impact on Naval message communications. It follows that as additional command and control capability becomes available on certain ships, the volume of message traffic that they handle will rise. Some of the aggregate ship classes we have defined (CV's, larger CG's, LCC's, etc., AD's and AS's) may thus experience some growth. Other classes, for which little additional capability is planned, will probably experience little or no growth in message processing volumes. Since these smaller ships are more numerous than the larger ships, we do not expect the overall traffic volumes (such as might charactize the broadcast) to grow nearly as fast as volumes for command-capability ships.

Another often cited cause of message growth is the reduced costs of sending messages due to increased automation and communications bandwidth. However, as we discuss in our effectiveness analysis, automation will not reduce the full cost of a message (i.e., the cost

including message preparation time and processing delays) by a very large amount. Since this cost is not reduced, we cannot expect traffic to grow significantly from this alone.

2. Predicted Message Volumes

These qualitative conclusions are somewhat helpful, but we have no way of quantifying the growth that will take place. Since, based on the discussion above, the principle cause of increased message volumes (per ship) will be increased command and control functions, we have increased our estimates of average daily volumes under routine operations by about 50% for the larger classes, and have made only modest changes for the other classes. This factor is admittedly an arbitrary one, corresponding to a growth rate of about 5% annually through 1986. Column 1 of Table IV-17 shows this forecast. As is also shown, we have adjusted our estimates of crises condition traffic to reflect increased 30-day peaks. Overall, average traffic under routine conditions rises 32% (average daily messages equal to 128 for all ships); while crisis traffic rises 22% (552 messages per day for all ships).

Given these overall increases, we can predict the change in broadcast and CUDIXS message volumes. Table IV-18 shows our predictions for the broadcast, while Table IV-19 shows our estimates for CUDIXS. From the tables, we can see that the worst-case traffic levels are about 4000 messages per day for the broadcast, and almost 13,000 messages per day for each CUDIXS network.

Table IV-17

Predicted Daily Message Loads

for 1980's

Ship Class	Routine Conditions	Crisis Conditions
Combatants		
Carriers (CVA, CV, CVN, CVT)	600	2600
Larger Cruisers (CG & CGN)	750	3100
Smaller Cruisers(CG & CGN)	120	700
Destroyers (DD & DDG)	75	320
Frigates (FF & FFG)	60	200
Amphibious Warfare Ships		
LCC, LHA, LPH & LPD	270	1300
Other (LKA, LSD, LST, etc.)	60	250
Auxiliaries		
Destroyer Tenders (AD)	350	1300
Combat Stores Ships (AFS)	150	500
Submarine Tenders (AS)	210	1000
Other (AE, AO, AOE, etc.)	75	350

Table IV-18

Predicted Broadcast Message Volume in the 1980's

Condition	Messages/Day	Million Characters/Day
Average, routine conditions	1700	2.6
Monthly peak routine conditions	2600	3.9
Crises conditions	4000	7.7

Table IV-19

Predicted Traffic on CUDIXS in 1980's

No. of Ships Send Only	No. of Ships Two-Way	Condition	Messages/Day	Millions of Characters/Day
30	0	Routine	990	.46
25	5	Routine	1470	1.1
50	10	Routine	2930	2.3
60	0	Crisis	8560	6.4
25	5	Crisis	6330	7.9
50	10	Crisis	12700	15.8

E. Message Volumes Processed by NAVMACS

We are now ready to estimate the processing load on a NAVMACS configuration. To do this, we combine our estimated traffic volumes on individual ships with our estimates of broadcast message volumes. This is because a NAVMACS processor must perform almost as much work on a broadcast message that is not addressed to it as on a message that is. (While NAVMACS must also perform some processing on CUDIXS blocks that are not addressed to it, conversations with NAVELEX personnel indicate that this workload is negligible compared to the load imposed by the broadcast. Thus, in the analysis that follows, we have counted only messages sent to or from the ship. In effect, this amounts to treating CUDIXS as a special type of full period termination.)[1/]

To clarify our estimation procedure, we make the following definitions:

- B = Total broadcast message volume (messages per day)
- r_i = Message volume addressed to a ship in aggregate class i
- s_i = Message volume sent by a ship in aggregate class i
- θ_i = Fraction of broadcast messages addressed to ships in aggregate class i
- $t_i = r_i - \theta_i B$ = Message volume received by a ship either via termination or CUDIXS two-way channel.

Then the total amount of traffic that a NAVMACS configuration must process (say, V_i) is:

$$V_i = B + t_i + s_i$$

$$= (1-\theta_i)B + (r_i + s_i)$$

1/ Hence, we do not distinguish between the loads on NAVMACS configurations which are equiped to handle terminations and those which are not.

That is, NAVMACS must process all of the ship's own traffic ($r_i + s_i$) plus the non-addressed broadcast traffic $(1 - \theta_i)B$. Our estimates of own-ship traffic are given in Table IV-17 above. Because there will be only one 2400 baud satellite broadcast, any ship desiring to monitor any of the broadcast must monitor it all. 1/ Thus, there is no need to deal separately with specialized multi-frequency broadcast channels. Our estimates of B are therefore taken from Table IV-18 above.

To obtain our estimate of θ_i, the fraction of messages received by the ship that uses the broadcast, we use the ratio of r_i to B for the period January-August 1976. This ratio clearly overestimates the value of θ_i, since r_i measures all messages rather than just broadcast messages. As a result, we will underestimate the value of V_i. However, it will be recalled that until now we have made a series of assumptions that probably overstate the traffic estimates, so our final value for V_i is not necessarily an underestimate of the "true" volume that needs to be handled by NAVMACS.

Table IV-20 shows our estimates of θ_i using this procedure. In two cases (CV's and larger CG's), we believe the estimates are much too

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1/ As with the existing satellite system, there will not be an automatic re-run of broadcast messages, as was the case with HF. Messages will be re-transmitted only when a ship specifically requests it. Thus, there is no need to account for re-runs in predicting message processing volumes.

As for specific requests for re-transmission, the data which we have seen (provided by NAVTELCOM) indicates that the satellite channels currently provide message rates on the close order of 1%. This means re-transmissions overall will not be a great problem.

high, because according to the NAVTELCOM monthly reports these ships are almost always terminated, and receive a great many messages directly. Therefore, we have lowered our estimates for these two aggregate classes to 0.15 and 0.22 respectively. (That is, we have assumed that half of all messages sent to these ships travel over terminations.) We have also reduced our estimates of θ_i for AD's and AS's to 0.15 and 0.10 for the same reasons.

Table IV-20

Estimated Proportion of Broadcast Messages
Addressed to Each Aggregate Ship Class

Ship Class	Average Rec'd Volume 1/	Estimated θ_i 2/	Value Used to Produce Table IV-21
Combatants			
Carriers (CVA, CV, CVN, CVT)	282	.29	.15
Larger cruisers (CG & CGN)	427	.44	.22
Smaller cruisers (CG & CGN)	84.0	.086	.08
Destroyers (DD & DDG)	34.4	.035	.03
Frigates (FF & FFG)	20.9	.021	.02
Amphibious Warfare Ships			
LCC, LHA, LPH & LPD	136	.14	.14
Other (LKA, LSD, LST, etc.)	30.8	.031	.03
Auxiliaries			
Destroyer tenders (AD)	204	.21	.15
Combat stores ships (AFS)	87.5	.089	.08
Submarine tenders (AS)	119	.12	.10
Other (AE, AO, AOE, etc.)	69.1	.066	.06

1/ Source: Table III-2

2/ Column 1 divided by 978 messages per day, derived in Table III-8 above.

Based on these values, Table IV-21 shows our projections of the total message and character loads placed on NAVMACS processors during routine and crisis conditions. To see how these projections are arrived at, let us consider the figures for CV's. From Table IV-21 we have $\theta_i = 0.15$. Using our estimate of 1700 broadcast messages under routine conditions gives $(1 - \theta_i)B = (0.85)(1700) = 1445$. From Table IV-17, our estimate of total messages processed by the ship $(r_i + s_i)$ is 600. Thus our estimate of total messages processed is 2045 = 1445 + 600, which is 2000 to two significant figures. In order to estimate the number of characters processed, we use 1500 characters per broadcast message, so that (1500)(1445) = 2,167,500 characters are accounted for by messages not processed. Including messages processed, with an assumed length of 1200 characters each, adds another 720,000 characters, for a total load of 2,887,500 characters, or 2.9 million to two digits.

Table IV-21

Predictions of NAVMACS Processing Loads

Ship Class	Routine Conditions Messages per Day	Routine Conditions Millions of Characters per Day	Crisis Conditions Messages per Day	Crisis Conditions Millions of Characters per Day
Combatants				
Carriers (CVA, CV, CVN, CVT)	2000	2.9	6000	11.4
Larger cruisers (CG & CGN)	2100	2.9	6200	11.8
Smaller cruisers (CG & CGN)	1700	2.5	4400	8.3
Destroyers (DD & DDG)	1700	2.5	4200	8.0
Frigates (FF & FFG)	1700	2.5	4100	7.8
Amphibious Warfare Ships				
LCC, LHA, LPH & LPD	1700	2.5	4700	9.0
Other (LKA, LSD, LST, etc.)	1700	2.5	4100	7.8
Auxiliaries				
Destroyer tenders (AD)	1800	2.6	4700	8.9
Combat stores ships (AFS)	1700	2.5	4200	7.9
Submarine tenders (AS)	1700	2.5	4600	8.7
Other (AE, AO, AOE, etc.)	1700	2.5	4100	7.8

As can be seen from the table, during routine operations the broadcast dominates the load for all but the largest ships. During crisis operations most aggregate classes are handling at least 100 messages per day by other modes than broadcast, and the large ships (CV's and CG's) are handling a substantial proportion of their total traffic by these other modes.

The development of Table IV-21 completes our analysis of Navy message traffic as it affects NAVMACS. The next step in our analysis is to compare the traffic loads that will be offered to a NAVMACS configuration to its capacity for processing that load. This comparison is the subject of the next chapter.

CHAPTER V

EFFECTIVENESS OF THE NAVMACS PROGRAM

We now shift our focus from the traffic loads placed on various aggregate ship classes to a discussion of the impact of the NAVMACS systems on the effectiveness of Navy afloat message processing. Our analysis is concentrated on what we believe to be the most important change in effectiveness due to NAVMACS: reduced message delay and/or increased message throughput.

In looking at the throughput/delay improvement associated with NAVMACS, we have been unable to perform as complete and quantitative analysis as we would have liked, because the available information on NAVMACS' performance is inadequate. However, we have been able to put some useful bounds on the improvement associated with the program. These bounds lead us to three conclusions:

1. The V2 (A+) and V3 (B) configurations of NAVMACS appear adequate or more than adequate to handle all projected Navy message communications, including communications during a crisis.
2. The V4 and V5 configurations may not provide significant additional improvements.
3. Automation using any NAVMACS configuration may not reduce the overall writer-reader delays by a very large

amount. The real bottleneck in the Navy's message processing system does not lie in the communications link, but in the afloat and ashore communications stations which process hard copies of messages.

These points, as well as our analysis of additional possible changes in effectiveness are discussed in the following sections.

A. Summary of Possible NAVMACS Program Effectiveness Changes

The available documentation on NAVMACS suggests a number of possible benefits associated with the introduction of automated afloat terminals. As is to be expected in a program which is continually evolving, there is a certain amount of overlap between many of the categories discussed in these documents. Overall, however, we believe that the following list summarizes the main effectiveness changes that may be brought about by the NAVMACS program:

1. Reduced message processing delays and/or increased throughput. All NAVMACS systems, through their CUDIXS interface, can send and receive traffic via a satellite. As noted in Chapter II, CUDIXS substitutes for full period terminations on small ships. NAVMACS also coordinates the receipt of broadcast messages via a 2400 baud link, and the V3, V4 and V5 versions support full period terminations. In all of these cases the higher channel speeds, and the use of faster output devices aboard a ship, allow for a more rapid processing of messages.

2. Better channel utilization. One result of the increased device speeds aboard ship is to allow the satellite channel to be operated at a higher bandwidth.

3. Cost Savings. Because messages not addressed to the ship are not printed, consumable cost savings may occur. These are treated in Chapters VI and VII below, which deal with our cost analysis.

4. Reduced Errors. Use of a satellite channel reduces message error rates compared to those incurred via HF radio. In addition, the introduction of KVDT devices for message composition may reduce operator errors over the current paper tape/TTY system.

5. Automated journaling and logging of messages.

6. Reduced delay for the composition of ship/shore messages. NAVMACS V3 and especially the larger configurations (V4 and V5) allow messages to be composed on-line, and automatically dispatched. This may result in time savings over the current system.

As can be seen from this list, the major impact of NAVMACS will be reducing the time required to pass messages from shore to ship or ship to shore. Reduced delay and/or increased throughput are involved in points

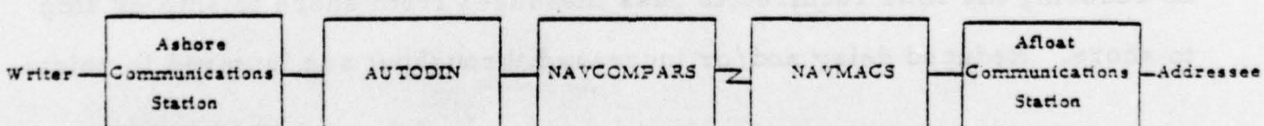
1, 2, 4, 5 and 6 above. While we believe that the list may be double-counting some benefits, it is clear that the delay/throughput issue is the most important one in assessing NAVMACS' effectiveness.

1. NAVMACS and Overall Navy Message Processing

In order to assess the impact of NAVMACS on message throughput and delay, we need to consider where the system fits in the overall Navy message communications system. Figure V-1 presents a schematic of the steps associated with ship/shore/ship message processing. As shown in the figure, shore/ship messages move from the originator to his communications center. After conversion to machine readable form (either by manual means or by OCR), messages pass via AUTODIN to the NAVCOMPARS unit for routing and transmission. Transmission may take place via the broadcast, full period termination, or CUDIXS.

Figure V-1

Overview of Shore/Ship Message Processing



NAVMACS receives the message via one of these channels, identifies it as being addressed to that ship, and prints it out. NAVMACS' error checking insures that the message is generally a clean one, and performs certain journaling and/or logging of the messages. Once printed out, the message must be duplicated and delivered to the afloat addressee. The process for sending ship/shore or ship/shore/ship messages is essentially the same as the process for shore/ship messages, except that NAVMACS V3(B) and larger configurations provide for on-line entry of the message, eliminating the need to prepare a paper tape.

2. A Simple Model of the Navy's Message Processing System

The basic elements of the Navy's message communications system shown in Figure V-1 can be thought of as involving a sequence of delay activities, each of which requires some processing and possibly some queuing. The activities are linked by communications channels along which messages are routed. The main point to notice about these linked activities, whether with or without NAVMACS, is that the end-to-end (or writer/reader) delay for a message is made up of the sum of the delays of each of the elements of the system. In a network such as this, one or two elements generally form a "bottleneck" and contribute most of the delay. The existence of these bottlenecks has two important implications when we assess the effectiveness of the NAVMACS systems:

1. If NAVMACS is not replacing one of the bottlenecks in the communications system, there will be little or no improvement in the overall delay associated with a message.

2. If NAVMACS does replace a bottleneck, the improvement in throughput and/or reduction in delay will only occur until a NAVMACS configuration is used with a capacity large enough for some other node in the network to become saturated, and act as a new bottleneck.

In effect, the existence of bottlenecks and potential bottlenecks in the network results in diminishing returns to increased capacity for any given node in the system. Only by a "balanced" increase in capacity can one avoid the problem of saturating a single node while the rest of the network can still function effectively. (A balanced network has all its nodes equally utilized, so that none of them saturates before any other.)

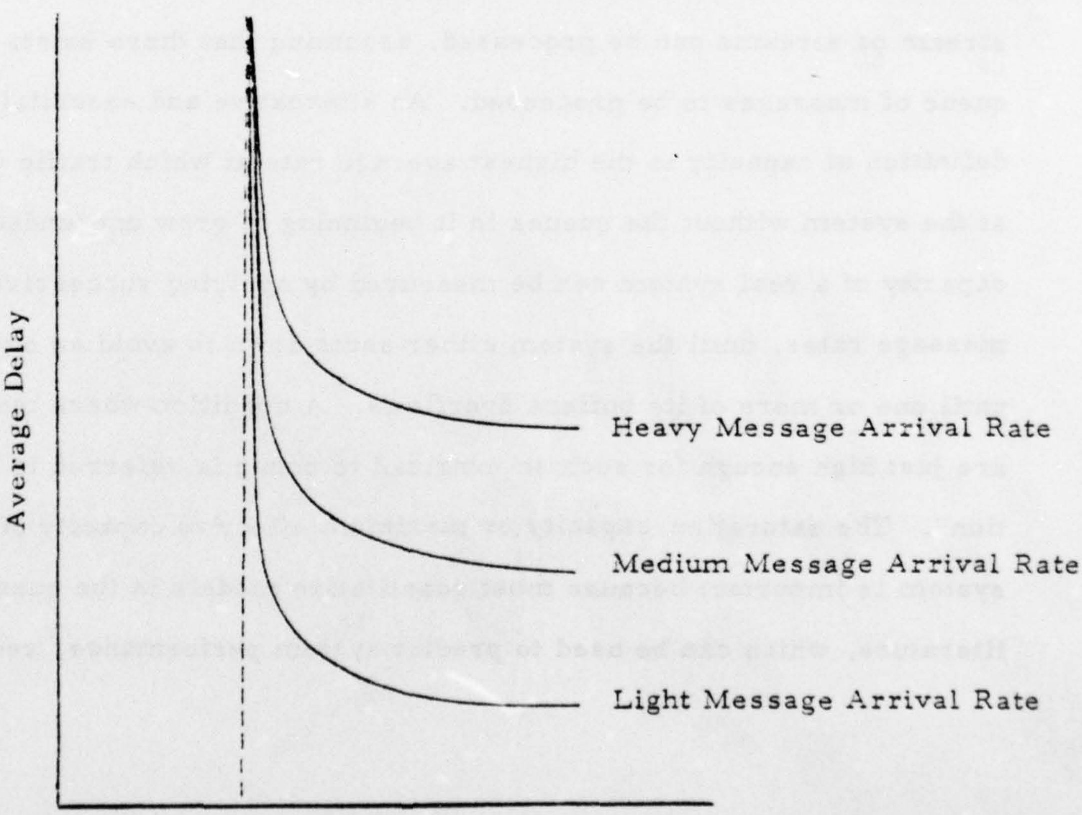
We can depict the relationship between cost and delay by a diagram such as Figure V-2. The figure is drawn so that capacity (proportional to cost) is changed at one node (the bottleneck node) only. As can be seen from the figure, there is a minimum capacity (cost) that must be available if any load is to be carried. This minimum level is given by the vertical dashed line. Also, there is a minimum delay associated with any particular message arrival rate, whatever the capacity of the node. This is because eliminating the delay at any particular node, even with an infinite expenditure on capacity, leaves the rest of the network unchanged. Thus a potential bottleneck becomes a new bottleneck. [1/]

1/ Trade-off curves such as shown in Figure V-2 are implications of the Kleinrock "square root" investment rule. See L. Kleinrock, Communications Nets: Stochastic Message Flow and Delay, (New York: Dover Publications, Inc., 1964).

From the point of view of our analysis of NAVMACS, Figure V-2 reinforces the two points made above. If NAVMACS is not in fact expanding the capacity of the bottleneck, it should have almost no effect on the minimum delay associated with any particular arrival rate for messages. And, if NAVMACS does alleviate a bottleneck we cannot necessarily expect dramatic reductions in message delays, because some other part of the Navy's communications system may not be far from saturation.

Figure V-2

Relationship Between System Cost and Response Time, When Capacity is Changed at One Node Only



B. NAVMACS Capacity Analysis

In order to see what NAVMACS' effect on bottlenecks is, we now look at the various NAVMACS configurations. First, we ask whether or not the capacity of a NAVMACS configuration is much lower, about the same, or much greater than the capacity of the communications channels to which it is connected. If NAVMACS has ample capacity compared to the communications channels, we expect its operation at heavy load to be limited by these channels, rather than by its own internal operation.

1. Capacity of NAVMACS Configurations

Some of our questions could be answered if we can determine the "capacity" of the various NAVMACS systems. By capacity, we mean what is sometimes called the maximum effective throughput of the processor. One definition of this capacity is the maximum rate at which a message stream or streams can be processed, assuming that there exists an infinite queue of messages to be processed. An alternative and essentially equivalent definition of capacity is the highest average rate at which traffic can arrive at the system without the queues in it beginning to grow unboundedly. The capacity of a real system can be measured by applying successively higher message rates, until the system either shuts down to avoid an overload or until one or more of its buffers overflows. A condition where message rates are just high enough for such an overload to occur is referred to as "saturation". The saturation capacity or maximum effective capacity of the system is important because most quantitative models in the queuing theory literature, which can be used to predict system performance, require this

value as an important system performance parameter.

As indicated in Chapter II, each of the NAVMACS configurations has a stated capacity. Table V-1 summarizes these values, as we have taken them from documents made available to us. However, the term "capacity" as used in these documents does not refer to the maximum value defined above, but to a minimum value. This is because the stated capacities represent the message rates that must be processed during a NAVMACS configuration's acceptance test.

For example, the stated capacity of a NAVMACS V3(B) is 2000 messages per day. However, the specification for NAVMACS V3(B) also requires successful operation at twice that rate (e.g., 4000 messages per day) for two hours. 1/ The specification calls for all messages to be processed with delays below certain levels at the 24 hour rate. For the two hour test, a backlog may develop. However, this backlog has to be cleared within the following two hour period, with the system also receiving messages at the 24 hour rate.

Viewed as a minimum value, rather than a maximum value, it seems obvious that the saturation capacities of the NAVMACS configurations are or will be significantly higher than the capacities stated in Table V-1. In addition to providing for surges, as tested in the specification, the system designers, who will necessarily be somewhat uncertain of the actual capabilities of their design, will undoubtedly leave a margin for error in passing the acceptance test. It would not be surprising to us if this safety margin were a factor of two greater than the two hour test rate.

1/ During our study, we were permitted to look at this document briefly, but not to copy or cite it in detail.

Table V-1

Nominal Capacities of NAVMACS Systems

System Name	Nominal Capacity (msgs/day)	Nominal Capacity (Millions of Characters per day)
V1	1100	2.2
V2 (A+)	1200	2.4
V3 (B)	2000	4.0
V4	3000	6.0
V5	5000	10.0

Source: From Table II-3

In fact, the two NAVMACS configurations that have currently been tested do appear to have saturation throughput levels greatly in excess of their nominal capacity. For example, the V2(A+) configuration has operated at approximately 6,000 messages per day when it was the only one using the CUDIXS satellite network. No backlog was reported during this experience. Also, a NAVMACS V3 aboard USS Josephus Daniels has successfully handled all the communications traffic for USS Nimitz, as well as its own traffic, while on deployment in the Mediterranean. No backlog or other difficulties were reported during this experience, which arose when Nimitz experienced a communications room failure.

However, it should be noted that neither the V2(A+) nor the V3(B) system have yet been tested to saturation systematically. Such testing, while not easy to do, appears to be within the capabilities of the existing test facility and we understand that plans are now being made to carry it out. (Such testing appears not to have been done until now in part because of the difficulty in specifying a "representative" set of test values to use.)

In the absence of extensive testing, the unintended capacity measurement reported above indicates that the existing NAVMACS configurations have saturation throughput levels much higher than their stated capacities. In the case of the A+ configuration, the multiple appears to be about five to one, or a capacity of about 12 million characters per day. 1/ As noted above, because of the way in which capacity is defined and tested, NAVMACS V4 and V5 may also be expected to have actual capacities in excess of their nominal capacities. 2/

2. Queuing Analysis of NAVMACS in Isolation

Before we consider the effect of NAVMACS when integrated into the rest of the Navy's message processing system, we can ask what the differential effectiveness of NAVMACS alone would be. To do this, we have calculated the delays and message backlogs implied by the 12 million character per day capacity derived in the preceding section for V2 (A+). The model we have used, while intentionally a very simple one, gives us a feel for the impact of V2 (A+) if it were installed on all ships.

1/ Source: Chief of Naval Operations, OP-961E1 Memorandum, 30 August 1977, Subject: NAVMACS Data.

2/ It should be pointed out that there are conditions under which either A+ or B can be stopped without the message arrival rate going to saturation. On both systems, there exists the possibility that a message will be requested from the magnetic tape storage. While the tape is being rewound, and the requested message extracted, it is impossible to record messages arriving at the terminal. As a result, it is possible to overload the system's buffers if the rewind is excessively lengthy. This is handled on current versions by restricting the amount of tape that can be used on any one cassette.

Also, it is known that NAVMACS V3(B) will cease responding to CUDIXS when it is handling the traffic from eight simulated broadcast channels. This problem is also due to limited buffer storage, and action is currently being taken to reduce the size of the operating system in order to make additional memory available for buffers.

In our calculation, we have employed the standard priority queuing model, originally solved by Cobham. 1/ This model assumes that messages arrive at the terminal with the precedence and length distributions described in Chapter IV, and are processed in a head-of-the-line, non-preemptive discipline. We have assumed exponential inter-arrival times for messages and exponentially distributed message lengths. Message loads are taken from Table IV-21. These assumptions are certainly unrealistic, but should result in conservative (i.e., overstated) estimates of system performance, because we know that broadcast messages arrive in a more regular pattern than exponential. We also have ignored possible buffer limitations on the NAVMACS systems, both because we understand that they are being corrected and because we are seeking only a rough guide to system performance. 2/

Tables V-2 and V-3 show the performance of a V2(A+) system, with an assumed capacity of 12 million characters per day, for each of our eleven aggregate ship classes, under both routine and crisis conditions. In the tables we have shown both the predicted backlog (in average number of messages) and the predicted delay (in minutes) for each of the four precedence levels, and for all precedence levels combined. Thus, on CV's and CVN's, we see that an average of .003 Flash messages will be backlogged under routine

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1/ A. Cobham, "Priority Assignment in Waiting Line Problems," Operations Research, Vol. 2 (1954), pp. 70-76.

2/ Our queuing calculations are greatly simplified by assuming there is no limit on how many messages can be stored. However, our backlog and delay analysis would not be greatly different if we took buffer limitations in the NAVMACS into account. This is because messages that are blocked due to lack of buffer storage are held in queues outside the system until the buffer can accept them. These "virtual" queues contribute to backlog and delay just as much as the physical queues contained in the system itself. Of course, since messages queued in this way require some additional processing, our calculations will slightly underestimate the backlog and delay.

Table V-2

NAVMACS V2(A+) Performance in Isolation -- Routine Conditions

Aggregate Ship Class	Daily Traffic[1] (Millions of Characters)	Predicted Message Backlog & Delay by Precedence[2]				
		Flash	Immediate	Priority	Routine	Combined
CV & CVN	2.90	0.003 0.12	0.061 0.22	0.127 0.23	0.128 0.24	0.319 0.23
Large CG	2.90	0.003 0.11	0.061 0.21	0.127 0.22	0.128 0.23	0.319 0.22
Small CG	2.50	0.003 0.11	0.051 0.22	0.105 0.22	0.104 0.23	0.263 0.22
DD & DDG	2.50	0.003 0.11	0.051 0.22	0.105 0.22	0.104 0.23	0.263 0.22
FF & FFG	2.50	0.003 0.11	0.051 0.22	0.105 0.22	0.104 0.23	0.263 0.22
Large Amphibious	2.50	0.003 0.11	0.051 0.22	0.105 0.22	0.104 9.23	0.263 0.22
Small Amphibious	2.50	0.003 0.11	0.051 0.22	0.105 0.22	0.104 0.23	0.263 0.22
AD	2.60	0.003 0.11	0.054 0.22	0.111 0.22	0.110 0.23	0.277 0.22
AFS	2.50	0.003 0.11	0.051 0.22	0.105 0.22	0.104 0.23	0.263 0.22
AS	2.50	0.003 0.11	0.051 0.22	0.105 0.22	0.104 0.23	0.263 0.22
Other Auxiliaries	2.50	0.003 0.11	0.051 0.22	0.105 0.22	0.104 0.23	0.263 0.22

1/ Source: Table IV-36. **Assumes daily capacity of 12 million characters per day.**

2/ **Top number is average backlog in messages, bottom number is average delay in minutes.**

Table V-3

NAVMACS V2(A+) Performance in Isolation -- Crisis Conditions

Aggregate Ship Class	Daily Traffic[1/] (Millions of Characters)	Predicted Message Backlog & Delay by Precedence[2/]				
		Flash	Immediate	Priority	Routine	Combined
CV & CVN	11.40	0.096 0.39	0.736 0.59	2.438 1.50	17.463 16.76	20.733 4.98
Large CG	11.78	0.102 0.39	0.784 0.61	2.856 1.70	55.580 51.64	59.321 13.78
Small CG	8.36	0.059 0.32	0.424 0.46	0.843 0.71	1.035] 1.36	2.362 0.77
DD & DDG	7.98	0.055 0.32	0.393 0.45	0.748 0.66	0.838 1.15	2.034 0.70
FF & FFG	7.79	0.053 0.31	0.378 0.44	0.705 0.63	0.757 1.06	1.893 0.67
Large Amphibious	8.93	0.065 0.33	0.474 0.48	1.012 0.79	1.459 1.79	3.010 0.92
Small Amphibious	7.79	0.053 0.31	0.378 0.44	0.705 0.63	0.757 1.06	1.893 0.67
AD	8.93	0.065 0.33	0.474 0.48	1.012 0.79	1.459 1.79	3.010 0.92
AFS	7.98	0.055 0.32	0.393 0.45	0.748 0.66	0.838 1.15	2.034 0.70
AS	8.74	0.063 0.33	0.457 0.48	0.952 0.76	1.296 1.62	2.768 0.87
Other Auxiliaries	7.79	0.053 0.31	0.378 0.44	0.705 0.63	0.757 1.06	1.893 0.67

1/ Source: Table IV-36. Assumes daily capacity of 12 million characters per day.

2/ Top number is average backlog in messages, bottom number is average delay in minutes.

conditions, with an average delay of 0.12 minutes (about 7 seconds). The combined delay for all precedence levels will be 0.23 minutes (14 seconds) with an average of 0.319 messages backlogged. As can be seen from the table, NAVMACS V2(A+) easily processes all messages under routine conditions.

More interesting is its performance under crisis conditions. Here, using traffic levels developed in Chapter IV, we still find fairly comfortable performance margins for small ships. For large CG's, which are the nearest to saturation, the delay for Flash messages has risen to .39 minutes (or about 23 seconds). Overall almost 60 messages are backlogged on average, almost all of them at Routine precedence. Higher precedence messages can still get through. The average delay has risen to 13.8 minutes overall, or 51.6 minutes for Routines. Given existing guidelines for message processing these are all quite acceptable delays.

To reinforce this comparison, Table V-4 shows a comparison between the predicted performance of NAVMACS and the current estimates of daily backlog. A substantial reduction in the backlog is forecast, especially for the larger ships. However, it should be noted that the predicted backlogs are based on the assumption that all other parts of the Navy's message processing system have capacities greater than the capacity of the NAVMACS V2 (A+) making it the bottleneck in the system. If some other part of the system is the true bottleneck, the backlog reduction associated with NAVMACS may not be realized. In effect, the backlog will simply shift to the new bottleneck.

Even given this caveat, however, Tables V-2 through V-4 support one of the conclusions given at the beginning of this chapter. As indicated in the table, a V2 (A+) system is capable of processing even crisis level loads on all eleven aggregate ship classes. Even if our predictions are significantly

Table V-4

Comparison of Estimated Existing Backlogs

With NAVAMCS V2(A+) in Isolation
(Number of Messages, Routine Operations)

Ship Class	Estimated Average Daily Backlog Jan-June 1976 1/	Estimated Average Daily Backlog With NAVMACS 2/
Combatants		
Carriers (CVA, CV, CVN, CVT)	14.37	.32
Larger cruisers (CG & CGN)	12.49	.32
Smaller cruisers (CG & CGN)	4.03	.26
Destroyers (DD & DDG)	.75	.26
Frigates (FF & FFG)	.58	.26
Amphibious Warfare Ships		
LCC, LHA, LPH & LPD	6.31	.26
Other (LKA, LSD, LST, etc.)	.40	.26
Auxiliaries		
Destroyer tenders (AD)	1.47	.27
Combat stores ships (AFS)	5.92	.26
Submarine tenders (AS)	3.83	.26
Other (AE, AO, AOE, etc.)	1.15	.26

1/ Source: Table III-4

2/ Source: Table V-2

in error, the V3 (B) configuration should be capable of providing acceptable performance even on the largest ships. Thus, large message volumes alone are not in themselves a justification for the still larger capability of the V4/V5 configurations. And, on smaller ships (FF's, DD's and so forth), the full 12 million character capacity of the V2 (A+) configuration is unlikely ever to be used.

3. Capacity of Other Parts of the Communications Channels to NAVMACS

This leads us directly to the consideration of the capacities of other system components. We ask if it is in fact possible to send at a rate equivalent to 12 million characters per day for each V2(A+) aboard a ship.

It will be recalled from Chapter II that the V2(A+) system supports connection to one CUDIXS network, and to a 2400 baud broadcast satellite channel. The V3(B) system in addition allows up to 4 full period terminations, at 75 baud each. What are the effective rates of these communications channels?

This question, of course, cannot be answered simply by converting bauds to characters per second (cps), because there are inevitable overheads to be accomodated on each channel. For example, full period terminations involve operator coordination at both ends, as well as delays associated with changing paper, and retransmitting missed messages. At best, it seems reasonable to assume an operational efficiency that is no more than 80% of the theoretical limit. Using Baudot coding,[1/] this gives each TTY circuit a maximum operational rate of 8 cps. Similarly the

1/ This is the character set used on the satellite channels. (Mr. W. Wilcox, NAVELEX, personal communication.) With five bits of information, plus a start and stop bit, the conversion from bauds to cps is 1/7.5.

2400 baud broadcast circuit (with a 320 cps maximum rate using Baudot coding) is also subject to some overhead. Again, assuming 80% efficiency, the maximum rate at which the broadcast can send messages into the NAVMACS is 256 cps.

As we saw in Chapter IV, under routine conditions the broadcast may be expected to carry 1700 messages per day. (See Table IV-18). This is equivalent to 29.5 cps =(1700 messages per day)(1500 characters per message)/(86,400 seconds per day). Thus, the effective channel utilization is perhaps 12 percent. Under crisis conditions, the broadcast handles perhaps 4000 messages per day, or 88 cps when increased message lengths are allowed for. This gives a utilization of 34%, which is still a comfortable margin. Transmission times for a 1500 character broadcast message are about 6 seconds, with queuing delays adding about another 3 seconds. 1/ These times are comparable to the delays calculated above for the NAVMACS V2(A+) configuration, indicating that the broadcast channel does not constitute a significant bottleneck.

The CUDIXS network is more complicated to analyze than the broadcast. As we discussed in Chapter II, this system services users who wish to send or receive in a round-robin fashion. In order to coordinate the round-robin polling, overhead is required to transmit a sequence order

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1/ At 34% utilization, the average transmission delay will be roughly 6 sec (=1500/256). Delay in queue is this time, multiplied by .34/(1 - .34) = .52, assuming an M/M/1 queue. See, for example, L. Kleinrock, Queuing Systems, Vol. 1, (John Wiley & Sons, 1975), Chapter 3.

list (SOL) once during each polling cycle. Additional overhead is required for other data associated with the network protocol. Finally, garbled messages must be retransmitted until all ships in the network have received them. As a result, a detailed calculation of CUDIXS throughput rate is beyond the scope of this report.

However, we can make an approximate calculation for an important special case: when there are a full 60 ships using the net, split 10/50 between two-way and send only. In this case, the important point is that the effective channel capacity is divided roughly equally among the number of ships.1/ While the overhead in this case may be 20% of the total available capacity, the important point about the full-load case is that the remaining capacity is divided by approximately 60. Thus the overhead is unimportant compared to the actual throughput achieved per ship.

It is our understanding that CUDIXS itself is operated at 2400 baud, due to modem limitations. Thus, when 60 ships are sharing the net for message sending, overhead may take up 20% of the available capacity, leaving 256 cps to be divided among the 60 ships. This

1/ In effect when there are a great many terminals on the net, the system acts very much like a TDMA system. The best analysis of a system such as CUDIXS that we have found in the open literature is due to Binder. We have drawn on his analysis for our remarks in this section. See: R. Binder, "A Dynamic Packet-Switching System for Satellite Broadcast Channels," ICC 75 Conference Record, Vol. 3, June 16-18, 1975, San Francisco, California, pp. 41-1 to 41-5.

gives an effective rate of approximately four cps. Notice that even if there were no overhead whatsoever, the average available capacity per terminal would still be only five cps. At this low rate, a 1200 character message requires 250-300 seconds for complete transmission. (Because higher precedence messages receive preference in the round-robin queue, this time will be shorter for higher precedence levels and longer for lower levels.)

We can look at overall delays by using Table IV-19 above, which projects CUDIXS loads into the 1980's. As shown in that table, during routine conditions with a 25/5 ship network (i.e., 25 ships in send-only mode, and 5 ships in two-way mode), CUDIXS must process 1.1 million message characters daily. This works out to 12.7 cps, giving a utilization under routine conditions of about 0.05. However, under crisis conditions, with a 50/10 ship network, the load rises to almost 16 million characters per day (12700 messages per day, or 177 cps). Thus, overall utilization in these worst case conditions is about 0.69. In this case, queuing delays would be about 2.2 (=.69/(1 - .69)) times the message's transmission time. Overall delays would be around 15 minutes -- much larger than the delays due to the NAVMACS terminal. Hence, at least when CUDIXS is fully loaded, its channel, and not the NAVMACS processor, is the source of most of the delay.[1/]

1/ Of course, when there is only one ship on the CUDIXS network, it is possible to send enough traffic so that it and the broadcast together can probably saturate a V2(A+) configuration. However, given that FLEETSATCOM supports only two CUDIXS networks (see Chapter II) it is difficult to envision circumstances when one ship would have a net all to itself.

The analysis in the last few pages indicates that the V2(A+) or V3(B) configurations may reduce delays to the point where channel capacity (specifically the speed of the CUDIXS channel) becomes a limiting factor. This means that more powerful configurations (V4 and V5) will probably not provide additional reductions in delay because of limitations in the communications channels. In short, we have probably reached the point of diminishing returns with the V2 or V3 verions of NAVMACS, and the V4 and V5 versions appear unlikely to produce additional large improvements in effectiveness.

4. <u>Effective NAVMACS Delay on End-to-End Message Delay</u>

We now turn our attention to the final question of whether even the V2(A+) will have any major impact on the end-to-end (writer-reader) delays associated with a message. In order to make this assessment, we need data on the delays associated with other components of the Navy's message processing system. Such data are very scarce. The only information of which we are aware comes from a special study performed by NAVTELCOM. Table V-5 shows this information. As can be seen, communication center delays in reproduction and distribution together account for almost three hours of delay. AUTODIN and NAVCOMPARS broadcast delays account for about 3/4 of an hour of delay.

Table V-5

Some Component Speeds of Service

for Priority Messages

Source	Time Interval*	Average Delay (Minutes)
NTCC (A)	TOR-TOT	124
AUTODIN (B)	TOR-TOD	10
NAVCOMPARS Broadcast (C)	TOR-TOT	32
Reproduction and Distribution (D)	Mat Printer-TAD	44

Sources: Per NAVTELCOM

(A) Breezy Point (Manual), Hampton Roads (OCR), Portsmouth (Manual), Feb. 1976.

(B) AUTODIN Subscriber Management Analysis (ASMA) Report, April 1976.

(C) NAVCOMPARS, 1st Half 1976.

(D) Norfolk, all precedence levels combined, September 1975.

* TOR = Time of Receipt
TOT = Time of Transmission
TOD = Time of Delivery
TAD = Time Available for Delivery

Not shown in the table are the delays from the time a message is transmitted until it is received correctly aboard ship and prepared for reproduction. At the eight cps rate associated with the current 75 baud broadcast, transmission of a 1500 character message requires about 3.2 minutes. Over the 2400 baud broadcast, this time is reduced to about 5 seconds, but in either case it is clearly a trivial proportion of the end-to-end delay. Similarly, the time required to prepare the message for reproduction should not be greatly reduced under the current NAVMACS

system. Once a broadcast message has been recognized as addressed to a ship on the printer, the manual steps that need to be taken are the same whether NAVMACS is in place or not. In our comparison below, we have included these steps in the reproduction and distribution time estimate of 44 minutes.

Table V-6 shows a pair of estimates for the current delay for a Priority precedence shore/ship message. In one column is our estimate for the current system, while another column contains an estimate for NAVMACS V2(A+). However, in both cases we know there is some queuing delay to be allowed for. Looking again at Table V-4, we see that existing ships have combined backlogs from one to fifteen messages. Taking four messages as a typical level gives us, by Little's result, an afloat terminal

Table V-6

Estimated Total Delay for a Priority Shore/Ship Message

	Estimated Average Delay (Minutes)	
Source of Delay	Current System	NAVMACS A+
NTCC	124	124
AUTODIN	10	10
NAVCOMPARS	32	1
Afloat Terminal	10	.1
Reproduction and Distribution	44	44
Total	220	179.1

delay of 10 minutes for the current system. [1] Similarly, the average queuing delay for the NAVMACS system involves an average backlog of .2 to .3 messages, increasing the delay from .08 minutes to .1 minutes.

In addition to reduced delays at the afloat terminal, we expect some reduction in NAVCOMPARS delay due to the introduction of a single 2400 baud broadcast, instead of sixteen 75 baud broadcast channels, as is presently the case. For the sake of making a point we have set this value to one minute in Table V-6.

If we now add up the delays for the current and existing system, we find that the current system has an estimated end-to-end delay of 220 minutes (three hours and 40 minutes) while the estimated delay with NAVMACS is 179.1 minutes (or about 3 hours). Thus, even under favorable assumptions about the impact of NAVMACS on NAVCOMPARS and afloat terminal delays, we find that the overall reduction in end-to-end delay due to NAVMACS is not very great: about 19% even under these extremely favorable assumptions. A more reasonable value is probably closer to 10%, or about 20 minutes out of three hours and 40 minutes.

What we are seeing, of course, is our bottleneck phenomenon again. Most of the delay in the Navy's message processing system occurs at its ends. The longest delay (over 2 hours on average) occurs in getting the message coded and ready to transmit via automated systems. An additional

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1/ Little's result states that the average number of items in a work conserving queue is equal in equilibrium to the product of the rate at which messages arrive at the queue and the average delay per message. The result is an extremely general one. See: J. D. C. Little, "A Proof of the Queuing Formula $L = \lambda W$," Operations Research, Vol. 9 (1961), pp. 383-387.

delay occurs when it is desired to reproduce and distribute the message. Faced with these long delays, which are not affected in any important way by NAVMACS' message processing capability, the overall gain from the introduction of NAVMACS is surprisingly small. As we discuss below, however, the automated entry capability of the larger configurations does address the shipboard side of the problem, for ship-shore messages. But, by definition, these systems can do nothing to assist in reducing the reproduction and distribution delay that occurs in shoreside communications stations.

5. Summary of Delay-Throughput Analysis

As a result of the analyses discussed above, we can reach two conclusions. First, NAVMACS V2(A+) appears to have sufficient capacity to handle messages even during crisis conditions. Even if NAVMACS V4 and V5 have saturation throughput levels considerably in excess of the level for V2 and V3, there does not appear to be any reason to add these systems to the fleet. Second, we have seen that NAVMACS alone may not make a significant dent in the end-to-end message delays for the Navy. This is because the bulk of delay is incurred in the manual operations at either end of the message communication system, and not in the automated functions. As a result, even a perfect (i.e., zero delay) automated system would produce only about a 20% reduction in overall average delay for priority messages under routine conditions.

C. Other Issues Relating to Effectiveness

In Section A of this chapter we outlined several other arguments that had been made in favor of the NAVMACS systems. These included: better utilization of the satellite channel, cost savings, automation of

journaling and logging functions, and reduced errors. We now discuss these briefly.

The better utilization of the satellite channel is partially included in our delay analysis above, because we have allowed for the use of higher communications rates when NAVMACS is installed. Moreover, by providing the computer capacity to operate a sophisticated satellite communications algorithm, NAVMACS may postpone the saturation of satellite channels as system usage grows. For example, we have been told that only software modifications are necessary to replace the current TDMA (Time Division Multiple Access) version of the CUDIXS algorithm with a more efficient DAMA (Demand Assigned Multiple Access) algorithm. However, no detailed projections of the improvements in efficiencies for either algorithm over the current arrangement are available, and so it is not possible to determine when a savings in satellite channels will occur. Similarly, we do not know the costs of any software changes. Therefore, our cost analyses (discussed in Chapters VI and VII below) assume no cost savings associated with improved channel utilization.

The automated journaling and routing, and the reduced message error rates, also do not appear to us to have significant improvements in effectiveness, other than an impact on delay. This is because, under current programming, there is no change in manning associated with the overall communications operation. Some operators on some ships may be burdened less than they are now. However, in the case of NAVMACS the relationship between the possible reduced loads and increased reliability or reduced error rates has not been substantiated. Nor is it clear, if there are such increases,

that NAVMACS is the best way to achieve these improvements. It may be that improved training, or improvements in communications operations and input equipment, without the use of a time-sharing system, could have as much impact on error rates as NAVMACS.

The automated entry feature of NAVMACS V3, V4, and V5, deserves some further comment. Insofar as both the current system and the KVDT system on NAVMACS are concerned, the speed with which written messages are transcribed into a machine readable form is as much dependent upon the training and dexterity of the operator as it is on the system in use. 1/ The principal advantage of the KVDT over the TTY/torn-tape system is the ease with which corrections can be made. In effect, by providing a buffer memory for the operator, the automated entry system of NAVMACS divorces him from the "recorded" document.

This suggests that the NAVMACS KVDT's, while they provide improved entry capability, may not be the most cost-effective solution. Stand-alone units, similar to commercial key-to-tape or word processing systems, are capable of providing the equivalent buffering for the input and editing of a message, and produce a machine-readable output. Such systems may be more cost effective than the dedication of NAVMACS' capacity to the automated entry capability. This is an important consideration because, as discussed below, much of the increased cost associated with the V4 and V5 systems appears to be due to the need to support a number of on-line KVDT's in a time-shared mode.

1/ For a discussion of the importance of training and dexterity compared to equipment in data entry, see M. Phister, Jr., Data Processing Technology and Economics (Santa Monica, California: Santa Monica Publishing Co., 1976).

1. Cost of NAVMACS' Message Entry Capability

In order to evaluate the message entry capability of NAVMACS V4 and V5 we need some idea of its cost. Since life cycle costs are difficult to estimate, the procurement costs of the different configurations (shown in Table II-2) have been used. Figure V-3 plots this cost against the maximum number of on-line terminals supported (also shown in Table II-2). The line shown in the figure is a least squares fit to the data, with the following equation:

$$\underset{}{COST} = 100 + \underset{(9.95)}{23.1\ (TERMS)} + \underset{(2.08)}{124.\ (PTRDUM)} \qquad \bar{R}^2 = .97$$

where:

COST = Procurement cost in thousands of dollars,

TERMS = Maximum number of terminals supported, including local and remote KVDT's, but excluding the operator's console,

PTRDUM = 1 if the configuration includes line printers, and 0 otherwise,

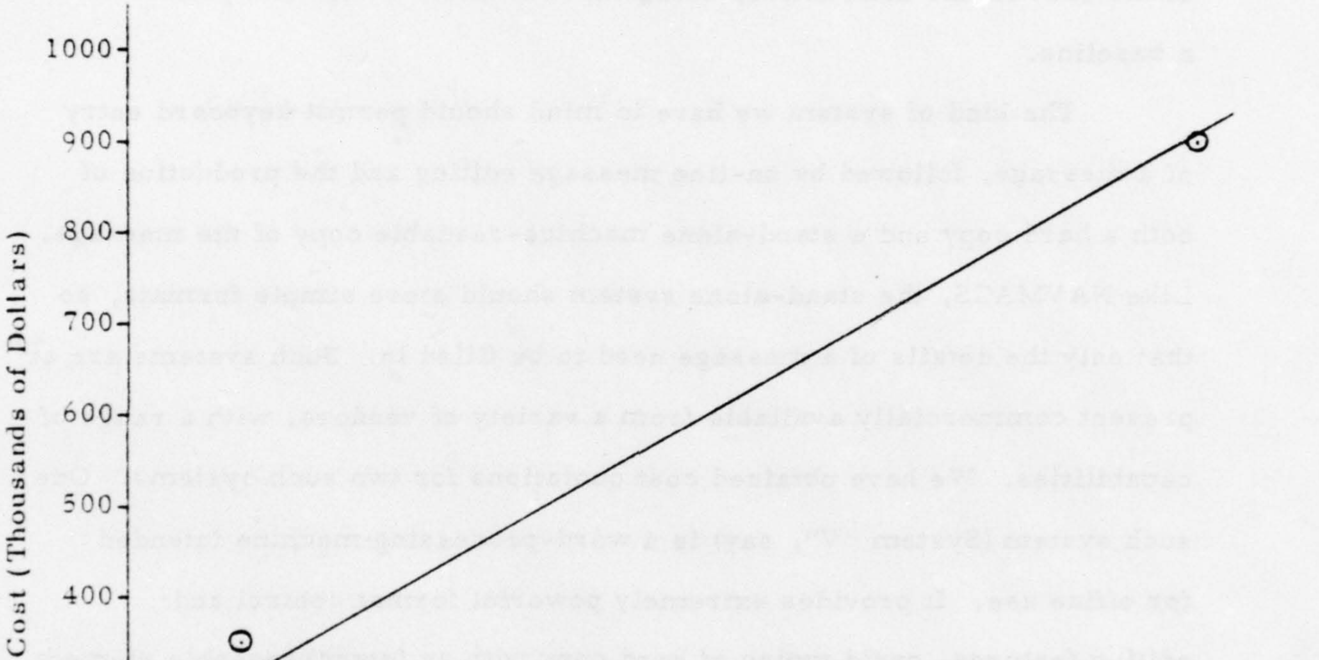
$\bar{R}^2$ = Coefficient of correlation (a value of one indicates perfect correlation, and a value of zero indicates no correlation), adjusted for degrees of freedom,

and the student-t values of the estimated coefficients are given in parentheses. The equation says that the first cost of a NAVMACS increases by about \$23(±2.3) thousand with each additional terminal that must be supported. 1/

1/ Of course, it is dangerous to rely too much on a regression with so few data points. However, it is interesting to notice that using the capacity of a NAVMACS configuration did not provide as much explanatory power.

Figure V-3

NAVMACS Cost Versus Terminals Supported



2. Cost of Commercial Word Processing Equipment

In contrast to NAVMACS' built-in message entry capability, one could consider placing stand-alone key entry (word processing) equipment aboard ship. Some non-pecuniary advantages to this approach are discussed below. In this subsection, we present some rough estimates of the cost of this alternative, using commercially available systems as a baseline.

The kind of system we have in mind should permit keyboard entry of a message, followed by on-line message editing and the production of both a hard copy and a stand-alone machine-readable copy of the message. Like NAVMACS, the stand-alone system should store simple formats, so that only the details of a message need to be filled in. Such systems are at present commercially available from a variety of vendors, with a range of capabilities. We have obtained cost quotations for two such systems. One such system (System "V", say) is a word-processing machine intended for office use. It provides extremely powerful format control and editing features, rapid typing of hard copy with an interchangeable element, and a pair of "floppy" disks, each of which can hold 60 pages of 8 1/2 x 11 text. (One of these disks could be used to hold the machine readable copy of each message.) It can store pre-formatted items, and can be programmed to handle a variety of editorial and error checking tasks. The quoted purchase price of the unit is $17,600 (as of November 1, 1977), and it is available for rent at $590 per month, including maintenance.

The second system (System "S") is a more basic system, assembled from commercial microprocessors and other off-the-shelf components. It's main features are shown in Table V-7. This system has the capability to

Table V-7

Features and Costs for "System S," a Microprocessor-Based Word Processing System

Processor:	16 bit microprocessor 24K RAM, 680 ns cycle time 256K floppy disc, 30 ms average access time Serial interface	$3800
Software:	Operating system and editor	included
Terminals:	Video display terminal 30 cps printer (including a second interface)	900 1700
Message Storage:	Data cassette drive and interface	600
TOTAL		$6900

accept and edit a message using a few simple formats, and with limited error checking. Hard copy output is on a 5 x 7 dot matrix printer, and a standard data cassette holds the message in machine-readable form. System S does not have as comprehensive an editor, and cannot type in as flexible a manner as System "V". However, it costs only $6900. 1/

Of course, neither of these systems is militarized or ruggedized, which in part accounts for their lower cost than NAVMACS. But since their

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1/ Since an 8 bit microprocessor is adequate for the character manipulation functions required of a word processor, we also considered an 8 bit system. Such a system, with dual mini-floppy disks, costs perhaps $1500 less than System S, but does not provide a sufficiently powerful editor for a word processing application.

costs are from 76% to 30% of the estimated cost of a NAVMACS-supported terminal, it seems quite likely that a stand-alone system that did meet military requirements would still be less costly. Moreover, since the stand-alone systems eliminate the need for wiring the terminals to the communications center, some of the fixed installation costs (not taken into account in this comparison) would also be saved.

3. Other Dimensions of the Comparison

Cost aside, there are several other dimensions to be considered in comparing a stand-alone system to NAVMACS. One advantage to the stand-alone system is that it provides additional control over the release of messages. Commanders who desire hard copy for correction or record-keeping purposes can receive this copy more rapidly in this case. Also, it may be possible to simplify security procedures somewhat, since the terminal no longer needs to be electrically connected to the processor.

On the other hand, the machine readable output of the stand-alone unit must still be carried to the communications center. This may itself pose security problems, and probably will not reduce the delay in dispatching a message (once it is released) as much as NAVMACS' KVDT's. Moreover, the NAVMACS terminals can receive messages, as well as send them. When terminals are distributed throughout the ship, as will be the case with the V5 configuration, this may reduce the delay on-board ship in distributing a message. However, we do not have any information on the effect NAVMACS will have on such delays at the present time.

On balance, the possibility that stand-alone word processing type systems may be more cost effective than the larger NAVMACS configurations (V4 and V5) should be investigated further. Stand-alone systems appear to have a cost advantage over NAVMACS as now conceived--possibly a considerable one. On the other hand, while both systems will probably reduce delays and improve control compared to the present system, NAVMACS may reduce delays more, especially for arriving messages.

CHAPTER VI:
COST ANALYSIS: METHODS AND ASSUMPTIONS

In the preceeding chapter we assessed the impact of different NAVMACS configurations on shipboard communications. The next two chapters provide analyses of the costs associated with the development and installation of alternative NAVMACS configurations. The present chapter describes the assumptions, methods, and factors that are used in the NAVMACS cost analysis. In the next chapter, we discuss the results obtained under alternative scenarios. The following sections are included in this chapter:

- Scope of the analysis
- Cost categories
- Cost factors

A. Scope of the Analysis

Any cost analysis is designed to provide information about the impact different decisions will have on the costs incurred as a result of a particular decision. In the case of the NAVMACS program, an alternative includes the configurations available and the schedule for their installation. We use the term "scenario" to describe this kind of alternative. Depending on the information desired, there are several ways such an analysis can be conducted. For example, the total costs under each of the alternative scenarios could be estimated and compared. Equivalently, one scenario could be selected as a baseline from which to measure the differential costs of other scenarios. The latter approach is simpler when all scenarios have many costs in common, and is the approach we take in analyzing the costs associated with the NAVMACS. Its details are discussed in the following paragraphs.

The baseline scenario that we have selected assumes that all installations of NAVMACS cease as of October 1, 1977 (i.e., none, including replacement of currently installed systems, occur during or after Fiscal Year 1978). The "cost" of the baseline alternative is normalized to zero. Therefore, less costly alternatives will have a negative "cost".

All costs associated with installations that occured in FY1977 and before are assumed sunk. One important implication of this assumption is that operations costs or savings (e.g., on consumable items, spare parts, etc.,) associated with pre-FY1978 systems which are incurred after FY1977 are assumed to be unavoidable unless there is a specific decision changing the baseline conditions. That is, under the baseline decision, these costs (savings) will be incurred (accrued).[1/] The only way to avoid them is to select a scenario where the current installations are removed (or turned-off) prior to the end of their economic life. Replacement of these systems, however, is not considered to be a part of the baseline decision, and, therefore, the investment costs and the operating costs (savings) associated with these replacements are included in the costs of the scenarios that we analyze. Many of the most important costs that are not avoidable as a result of any NAVMACS decision are those related to the satellite and and shore based communications systems. Therefore, none of these costs are included in our analysis.

In calculating costs, we have focused our analysis on the present value of costs, discounted to FY 1978. A present value is a weighted sum of future costs, where the weights reflect the smaller

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1/ It must be noted that some of the costs that we have assumed to be sunk (e.g., spares, consumables, etc.) have not all been paid and still represent future outlays. We are concerned, however, only with avoidable costs.

relative worth of a dollar next year compared to a dollar today.[1/] In calculating the present value of costs, we made several assumptions. First, the discount rate that we use is 10% as prescribed by OMB. Second, costs are assumed to be incurred at the beginning of the (fiscal) year. Third, the analysis runs from FY1978 through FY1995. The ending date was selected to allow all installations to generate services for at least ten years while terminating the analysis within a reasonable forecast horizon.

All costs are expressed in constant FY1978 dollars (as of October 1, 1977). Cost factors used in the analysis (if not already in such dollars) are inflated using the GNP implicit price deflator (up through 1976) and an assumed annual inflation rate of 5% per annum for future years. It is further assumed that there is no increase in <u>real</u> prices during the period of analysis, nor any change in <u>relative</u> prices (e.g., we assume that personnel costs are not growing relative to equipment costs). We make this assumption solely to adhere to current Navy practice regarding the use of inflation rates.

The economic life of NAVMACS system is taken to be 15 years.[2/] Therefore, individual systems are replaced 15 years after their installation. The use of an economic life for a system has two implications. First, some early installations will have to be replaced prior to FY1996, and these replacement costs (equipment and installation) are included in the analysis.

1/ Instead of expressing this weight directly, it is customary to use a "discount rate" which is essentially the interest rate applicable to government investments. If the discount rate is a constant r, the relative value of a dollar t years from now compared to a dollar now is $(1+r)^{-t}$.

2/ CNO, OP961E1 Memorandum, 30 August 1977, subject: NAVMACS Data

Second, many systems that are installed at the end of the time horizon will have some useful economic life remaining. Because much of the equipment in a NAVMACS (e.g., the AN/UYK-20 computer) can be used for other purposes, the costs associated with the unused portion of the economic life of this equipment should therefore be deducted from the total cost in the year following the analysis. The amount credited is the present value of the unused portion of the annualized equipment cost, discounted to the year following the end of the time horizon (i.e., the savings are credited in FY 1996).

This procedure can easily be illustrated by the following example. Consider a piece of equipment with a purchase cost of \$100 and an economic life of 15 years. With a 10% discount rate the annualized cost of the equipment is:

$$\left(\frac{.10}{1-\left(\frac{1}{1+.10}\right)^{15}}\right)(\$100) = (.1315)(100) = \$13.15$$

In other words, payment of \$13.15 annually for 15 years is equivalent, in present value, to an initial payment of \$100 assuming a 10% discount rate. If at the end of the time horizon, the particular piece of equipment had been in place only five years, there would be 10 years of "unused" economic life. We take as the value of that unused service the present value of \$13.15 over a period of 10 years or \$80.80. This amount is then "saved" or credited in the first year past the relevant time horizon. 1/

1/ To see that this procedure is appropriate, note that we could have used an annualized equipment cost in each year that a NAVMACS was installed. However, using the full equipment cost in the year of installation provides a more realistic picture of the investment outlays required.

These are the general assumptions underlying the cost analysis. In Section C below, the specific factors used to develop the cost estimates are provided. In the next section, the categories of costs that are considered relevant for this analysis are described.

B. Cost Categories

The first step in the cost analysis is to define the categories of costs that will be relevant for a cost analysis of the NAVMACS. Defining the cost categories provides an accounting framework for capturing all relevant costs, and presents additional information about the comparative cost of the scenarios. Two approaches could be taken to set up such a framework. First, all the costs associated with NAVMACS could be listed and grouped into appropriate categories. Second, a general, but well-established, list could be used as the basis from which the final list of categories can be derived. We have chosen the latter approach for two reasons. First, it increases the likelihood that all costs are captured since it is the product of several previous analyses. Second, it tends to lead to categories consisting of costs grouped in ways familiar to military planners. The list we have chosen for the basis of our analysis is a venerable one, taken from Fisher, et. al. at the RAND Corp., and reproduced here as Table VI-1. [1] As shown in Table VI-1, all the cost components can be grouped into three main categories: Research and Development (R&D) costs; Investment costs; and Operating costs.

1/ G.H. Fisher, et. al., "Costing Methods," in Analysis for Military Decisions, E.S. Quade (Ed.), (Chicago: Rand McNally, 1967) Table 15.2, pp. 272-3.

Table VI-1

Basic List of Potential Cost Categories

I. Research and development costs

- A. System development
- B. System test and evaluation
- C. Other system costs

II. Investment costs

- A. Installations
- B. Equipment
  1. Primary mission
  2. Specialized
  3. Other
- C. Stocks
  1. Initial stock levels
  2. Equipment spares and spare parts (initial)
- D. Initial training
- E. Miscellaneous
  1. Initial transportation
  2. Initial Travel
  3. Intermediate and support major command

III. Operating costs

- A. Equipment and installations replacement
  1. Primary mission equipment
  2. Specialized equipment
  3. Other equipment
  4. Installations
- B. Maintenance
  1. Primary mission equipment
  2. Specialized equipment
  3. Other equipment
  4. Installations
- C. Pay and allowances
- D. Training
- E. Fuels, lubricants and propellants
  1. Primary mission equipment
  2. Other
- F. Services and miscellaneous
  1. Transportation
  2. Travel
  3. Other (including maintenance of organizational equipment)
- G. Intermediate and support major command operating cost (only exceptionally included in cost analysis of individual systems)

In terms of our scenarios, these three main categories of cost (RDT&E, Investment, and Operations) are distinguished by the variables over which specific costs change. For example, RDT&E costs depend only on the

availability of a particular configuration, not on the number of systems installed. Investment costs depend on the number of systems installed but not on the length of time each system is installed. Operating costs (with the exception of software maintenance) depend on the number of systems installed and the length of time the systems are installed.

1. R&D Costs

Simply put, R&D costs consist of all costs incurred before a system is ready to be put into operational use. In this sense, R&D costs represent much more than purely scientific or technical effort. One example would be the training of instructors who are required in order to train the initial operators and maintenance personnel.

In Table VI-2, the components of cost we consider are shown in relation to the RAND components. (To make explicit the broad definition of R&D costs, we refer to them as Research, Development, Test, and Evaluation [RDT&E] costs.)

Table VI-2

Cost Categories for RDT&E Costs

RAND	NAVMACS Analysis
System Development	Software Development
System Test & Evaluation	Test & Evaluation
Other System Costs	Fixed Training

Since the NAVMACS hardware (with the possible exception of the V1 configuration) consists of "off-the-shelf" items, there is no R&D required for the hardware. Software must be developed for the V4 and V5 configurations and, most likely for the V1 configuration as well, so "Software Development"

is one of the cost categories that is included in this analysis.[1] As new configurations are developed they must undergo operational evaluation so that "Test and Evaluation" appears as the second category of RDT&E cost. Finaly, as noted in the example above, the training of instructors and the establishment of training schools is an RDT&E cost under the broad definition used here. Therefore, "Fixed Training" is a cost category replacing the "Other" category in the RAND list.

For NAVMACS V2 these R&D costs are considered sunk (or unavoidable).[2] For configurations V1, V3, V4 and V5, they are not sunk, however, so that any scenario which includes the installation of these newer configurations will incur some RDT&E costs.

2. <u>Investment Costs</u>

Investment costs represent those costs required to provide the capabilities of the new system to the organizational unit (in the case of NAVMACS, the ship). In Table VI-3 the cost categories used in this analysis are shown in relation to the RAND categories.

Table VI-3

Cost Categories for Investment Costs

RAND	NAVMACS Analysis
Installations	Installation Labor Incidental Materials
Equipment	Equipment
Stocks	Initial Spares
Initial Training	Initial Training
Miscellaneous	Miscellaneous Investment

1/ V1 software costs will be incurred to tailor existing software to fit the V1's smaller memory.

2/ Current plans call for additional V2 installations at schools. These are assumed to be required to support currently installed systems.

For the NAVMACS analysis, "Installation" is subdivided into "Labor" and "Incidental Materials" to reflect the nature of AMT 1/ and to provide additional information about cost. Installation costs include all costs (including wiring, interfaces, etc.) required to operate the NAVMACS. "Equipment" cost for the NAVMACS consists of the purchase cost of the modules comprising the individual configurations.

In place of a category called "Stocks", "Initial Spares" is used. This category contains the cost of providing the ship with sufficient repair items to perform their unit level maintenance tasks for the initial period of operation. "Initial Training" reflects those costs required to train the operation and maintenance personnel on board ship when the system is first installed and includes the costs of instructors used for this purpose. Finally, "Miscellaneous Investment" includes those investment costs not included in other categories.

3. Operating Costs

Operating costs are those costs required to operate and maintain the system aboard ship. Essentially, these are the costs that are incurred year after year rather than with the initial installation. In Table VI-4, the operating cost categories are shown for both this analysis and from the RAND list. The "Equipment and Installations Replacement" category is included in the investment costs, since these costs, like other investment costs, are incurred to provide continuing capability to a ship.

1/ Chief of Naval Operations, OP-436, "Amalgamated Military Technical Improvements," Washington, D.C., April 22, 1977, hereinafter cited as AMT.

Table VI-4

Cost Categories for Operating Costs

RAND List	For NAVMACS Analysis
Operating costs	
. Equipment and installations replacement - Primary mission equipment - Specialized equipment - Other equipment - Installations	(included in investment costs)
. Maintenance - Primary mission equipment - Specialized equipment - Other equipment - Installations	. Spares & Depot Maintenance
. Pay and allowances	. Pay & Allowances - Billets ET's RM's - Costs ET's RM's
. Training	. Training
. Fuels, lubricants and propellants - Primary mission equipment - Other	. Supplies (consumables)
. Services and miscellaneous - Transportation - Travel - Other (including maintenance of organizational equipment)	
. Intermediate and support major command operating cost (only exceptionally included in cost analysis of individual systems)	
	. Miscellaneous Operating Cost

Maintenance costs for the NAVMACS systems can be further subdivided. Unit level maintenance is performed by Electronic Technicians (ET's) whose costs are included in the "Pay and Allowances" category described below. In addition to the ET cost, there is also a cost for spare parts usage and for depot level maintenance support. We have included both of these under the "Spares and Depot Maintenance" category.[1/]

1/ Since there is no intermediate level maintenance function for NAVMACS, there is no category for intermediate level maintenance costs. Ref: Naval Electronics Systems Command, NAVELEX P4110.110, "Naval Modular Automated Communications, System 'A+'...", November 1976.

The category "Pay and Allowance" is divided into two parts. First, the number of billets affected by the installation is one category. The costs associated with these billet adjustments are included in the second category. Personnel costs are also divided into radioman (RM) and ET positions.

The "Training" category under operating costs is designed to account for the costs of training replacement personnel. In addition, it includes the cost (pay and allowances) for the instructors and the replacement training costs for instructors lost through attrition. The "Supplies" category includes the consumable items associated with the operations of the communications center (e.g., paper, ink, ribbons, reproduction, etc.). "Miscellaneous Operating" costs includes those operating costs not included in other categories.

C. <u>Cost Factors</u>

In this section, we discuss the cost factors used in preparing the cost analysis for NAVMACS. In developing these factors, information contained in Navy documents or provided by Naval personnel in response to our questions was used to the extent possible. For example, an OPNAV Memorandum[1/] provides answers to several questions and is used extensively below. (All references below to OPNAV Memorandum 30 August, 1977 are to this document.) For some factors, however, information in response to our inquiries has not, as of the time of this writing, been provided. Planning factors for other costs have not yet been developed. We therefore develop these cost factors based on plausible assumptions.

1/ CNO, OP-961E1 Memorandum 30 August 1977, subject: NAVMACS Data

In the next chapter, the sensitivity of our results to these assumptions is investigated.

1. RDT&E Costs

As discussed in Section B above, there are three categories of RDT&E cost: Software Development, Test and Evaluation, and Fixed Training. The software costs for systems V2 and V3 are considered sunk. The cost estimate for the development of software for systems V4 and V5 was provided as a single figure ($2.5 million).[1/] Since the two systems are to be available by FY 1981 (V5) and FY 1982 (V2), it would be expected that some of these costs would be incurred in the years FY 1978 through FY 1980. Without further information on their timing, however, we have assumed that all costs are incurred in FY 1980. The difference in present value for several different time patterns has been found to be insignificant. Software development for the V1 configuration has been estimated at $1 million incurred in FY 1978.[2/] This estimate is much less firm than that for the V4 and V5 configurations since the hardware to be used in the V1 configuration is not set.

Estimated costs for Test and Evaluation (T&E) are shown in Table VI-5. T&E costs for the V2 and V3 systems are sunk. Estimated T&E costs for the V1, V4, and V5 systems are to $100,000 for each configuration.[3/] Although the configurations vary with respect to cost and complexity, the same basic procedures are used. The T&E costs are shown in Table VI-5. We assume that the costs are incurred in the year prior to first installation.

1/ OPNAV Memorandum 30 August 1977.

2/ Personal communication with Mr. S. Lechter, OP-941J, 9/21/77.

3/ Ibid.

Table VI-5

Cost Factors for Test and Evaluation
(Thousands FY 1978 Dollars)

System	Year			
	FY 1978	FY 1979	FY 1980	FY 1981
V1	0	0	0	100
V2*	0	0	0	0
V3*	0	0	0	0
V4	0	0	0	100
V5	0	0	100	0

*Sunk

Source: See text

Fixed training costs consist of two main factors: equipment for schools and the training of the initial cadre of instructors. Equipment for the schools is also required for the V1, V3, V4, and V5 systems. Some additional V2 systems are also required for training. The costs of these systems are assumed to be unavoidable. The number of each of the configurations above those already committed that are required for training use is shown in Table VI-6. The number of V3 configurations required is based on informal budget data. Data on the V4 and V5 configurations were provided by OP-941J. 1/

Table VI-6

Number of New Systems Required for Schools

System Configuration	Number	Fiscal Year
V1	6	1980
V2	0	N.A.
V3	3	1978
V4	2	1981
V5	2	1981

Source: See text.

1/ Personal communication, Mr. S. Lechter, 9/21/77.

Costs for initial instructor training are based on the reported costs of training eight instructors for the V3 system. For 18 individuals, the course cost was \$8,000 or about \$450 per person. Total subsistance cost was approximately \$1,000 per person. The individuals in the course had been previously trained on V2 systems. These costs represent, therefore, the incremental cost of training an instructor for the V3 configuration. We assume that eight individuals each will be trained for the V4 and V5 systems. Therefore, contract and subsistance costs for the fixed training for V4 and V5 systems totals \$11,600 each.

The personnel cost for fixed training consists of three weeks salary and other costs per individual. The cost of these three weeks is based on the fact that of current maintenance instructors, 20 are E-6 while 8 are E-7.[1/] The average annual cost of a E-6 with an ET rating is \$18,306 while that of a E-7 is \$22,958.[2/] Therefore, the labor cost for 8 instructors being trained for three weeks is about \$9,100. Total fixed training costs for the V4 and V5 system each is, thus, approximately \$20,700. Although these systems are scheduled for installation in FY 1981 and FY 1982 respectively, we assume that these costs are incurred in the same year (FY 1981) that the V5 equipment is purchased. We assume that current instructors require no additional training for the V1 configuration.

Table VI-7 summarizes the costs for fixed training associated with each of the NAVMACS configurations. The equipment cost is based on the equipment cost factors given in Table VI-11 below. Installation costs for

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1/ Personal communication, LCDR. M. Ford, OP-940.

2/ See Section 3 below.

these training sites ashore are assumed to be zero since a major part of installation costs are incurred because of space limitations on ships.

Table VI-7

Fixed Training Costs
(Thousands FY 1978 Dollars)

System Configuration	Equipment	Personnel & Training	Total	Fiscal Year Incurred
V1	600	0	600	1980
V2	0	0	0	N.A.
V3	900	0	900	1978
V4	700	21	721	1981
V5	1796	21	1817	1981

2. Investment Costs

Investment costs are those costs associated with providing an individual ship with the services of a NAVMACS. The first category under Investment Cost is "Installation" cost. The source of these data was the AMT cited above. That document provides costs for much more detailed groupings than the eleven aggregate ship classes used in this analysis.1/ Therefore, we have developed average cost factors for each of the aggregate ship classes.

In Table VI-8, the cost factors for the Installation costs are presented. Column 1 contains the aggregate ship class defined in Chapter III above. In column 2, the ship classes defined in the AMT that were used in developing the factors are given. The number of installations in each of the aggregate ship classes is given in column 3. Column 4 gives

1/ Notice that for cost analysis purposes AGF-3 (U.S.S. La Salle) has been assigned to the LCC, LPD, LHA, LPH aggregate ship class.

Table VI-8

Cost Factors for Installation Costs

(1) Aggregate Ship Class	(2) Ship Classes Used	(3) Number Observed	(4) Daily Labor Rate ($/Man Day)	(5) Avg. Number Man Days/ Installation	(6) Average Incidental Materials (Thous. FY 1978 $)	(7) System Configuration
CV	CV43, CV63, CV64	3*	154	660	29	V3
LARGE CG, CGN	CG11	1	180	595	15	V2
SMALL CG, CGN	CG16, CG26, CGN25, CGN35	15	180	1030	21	V2
DD, DDG	DDG2, DDG31, DDG35, DDG37, DD931, DD933, DD945, DD948, DD963	67	180	833	18	V2
FF, FFG	FF1037, FF1040, FF1052, FFG1	37	180	812	21	V2
LCC, LHA, LPD, LPH	LCC, LPD, LPH.	25	174	2522	87	V3**
LCC, LHA, LPD, LPH	LHA	5	174	350	15	V2
OTHER AMPHIB. WARFARE	LPA	1	174	2034	70	V3
OTHER AMPHIB. WARFARE	LKA, LSD28, LSD36, LST	37	174	483	28	V2
AD	AD14, AD37	5	147	227	13	V2
AFS	AFS	7	147	1008	35	V2 → V3
AFS	AFS	5	147	321	18	V2
AS	AS(FBM), AS11, AS19, AS36GP	10	147	385	23	V2
OTHER A	ASR21, ASR7, AE, AO, AOR, AOE, AR	31	147	244	18	V2

Notes: * CVT omitted.

** Upgrades from V2 to V3 configurations and installations of new V3 configurations appeared with the same estimate of labor and materials required. To maintain conformity, we have taken the estimate appearing in the Table to be the cost of installing a new V3 configuration.

Source: AMT

the daily man day rate for each of the aggregate ship classes. In column 5, the average number of man days of labor required for the installation of the system configuration shown in column 7 is given. Column 6 contains the estimated incidental materials costs for the average installation within each ship class.

In Table VI-9, we summarize the results by aggregate ship class and by system configuration. In the first column, the aggregate ship class is given. In each of the other columns, the costs for labor (the upper part of Table VI-9) and for incidental materials (the lower part of Table VI-9) are given. The labor costs are found by multiplying the daily rate in column 4 of Table VI-8 by the number of man days of labor (column 5 in Table VI-8). The costs for installation based on the AMT data are noted in Table VI-9. Costs for other configurations are assumed to be the same as the costs for the closest (smaller) configuration for which we have an AMT estimate. Some support for this assumption is that in the AMT; several installations are noted as "NAVMACS B-C-D-E" with one figure for installation.

Note that these installation costs assume no previous NAVMACS has been installed. If a NAVMACS is currently installed, the costs of changing to another system will be different than if no NAVMACS was previously installed. If the new system is larger than the system it replaces (e.g., if a V2 is upgraded to a V5), then we assume that the installation cost (both labor and materials) is the maximum of (a) the difference in installation costs of the two configurations, or, (b) the cost of installing the V1 configuration which is taken to be a "minimum" installation cost. If the new configuration is smaller (e.g., if a V2 is

Table VI-9

Summary of Installation Costs
(Thousands FY 1978 Dollars)

Aggregate Ship Class	V1	V2	V3	V4	V5
a. Labor					
CV, CVN	102	102	102*	102	102
Large CG, CGN	107	107*	107	107	107
Small CG, CGN	185	185*	185	185	185
DD, DDG	150	150*	150	150	150
FF, FFG	146	146*	146	146	146
AGF, LCC, LHA, LPD, LPH	61	61*	439*	439	439
Other Amphibious Warfare	84	84*	354*	354	354
AD	33	33*	33	33	33
AFS	47	47*	148*	148	148
AS	57	57*	57	57	57
Other Auxiliaries	42	42*	42*	42	42
b. Incidental Materials					
CV, CVN	29	29	29*	29	29
Large CG, CGN	15	15*	15	15	15
Small CG, CGN	21	21*	21	21	21
DD, DDG	18	18*	18	18	18
FF, FFG	21	21*	21	21	21
AGF, LCC, LHA, LPD, LPH	15	15*	87*	87	87
Other Amphibious Warfare	28	28*	70*	70	70
AD	13	13*	13	13	13
AFS	18	18*	35*	35	35
AS	23	23*	23	23	23
Other Auxiliaries	18	18*	18*	18	18

Source: * AMT

All Other: See text.

downgraded to a V1) the installation cost is estimated to be the labor cost only for the V1 configuration.[1/] This is because the NAVMACS is considered to be modular so that no new fittings, wiring, etc. should be required. An example of these costs for one aggregate ship class, the large amphibious warfare ships (LCC's, LHA's, LPD's, and LPH's) is given in Table VI-10.

Table VI-10

Installation Costs for Replacement Systems
Aggregate Ship Class: LCC, LHA, LPD, LPH
(Thousands FY 1978 Dollars)

Old System	New System V1	V2	V3	V4	V5
V1	-	76	526	526	526
V2	61	-	526	526	526
V3	61	61	-	76	76
V4	61	61	61	-	76
V5	61	61	61	61	-

Equipment costs for each of the systems are shown in Table VI-11. In the top row of Table VI-11, we show the equipment costs for new installations. These are based on the costs discussed in Chapter II above. The equipment costs shown in Table VI-11 plus the incidental materials cost provided in Table VI-9 include all costs required to install a NAVMACS

1/ For the scenarios analyzed in Chapter VII below, no installations are ever downgraded.

and have it ready to operate. Equipment costs for upgrades are also provided in Table VI-11. The major upgrade costs (in terms of the actual scenarios analyzed) were provided by OP-941J. 1/ All others were estimated by taking the difference (i.e., the cost of a new V4 installation less the cost of a new V2 configuration) and using that as the estimate of upgrade cost. That this procedure is not unreasonable can be seen by comparing the estimates provided for three upgrades ($126 for V2 →V3, $698 for V2 →V5, and $572 for V3 →V5) with what our method would estimate these costs to be ($126 for V2 → V3, $724 for V2 → V5, and $598 for V3 → Note that there are no equipment costs for downgrades.

Table VI-11

Equipment Costs for Upgrades & Downgrades of Systems (Thousands FY 1978 Dollars)

Old System	New System				
	V1	V2	V3	V4	V5
None	100**	174**	300**	350**	898**
V1	-	74	200	250	798
V2	0	-	126*	176	698*
V3	0	0	-	50	572*
V4	0	0	0	-	548
V5	0	0	0	0	-

Source:
* Personal communication, Mr. S. Lechter, OP-941J, 9/21/77.
** Table III2
All Others: See text.

1/ Personal communication, Mr. S. Lechter, OP-941J, 9/21/77.

2/ It is important to note that, based upon these upgrade costs, it would be less expensive, in terms of equipment costs, to install a V2 first and then upgrade to a V5 (total cost would be $174,000 + $698,000 or $872,00 than to install a V5 directly. (Total cost would be $898,000). While this appears counter intuitive we have used these upgrade costs as representi the best available information.

Fixed logistics costs consist of both initial spare parts provided with the equipment and any incremental costs to the supply system that results from the NAVMACS program. Estimated initial spare parts are equal to the estimate of annual spare parts costs. [1] Therefore, initial spare parts are included in the spares and depot support described below since we assume all costs are incurred at the beginning of the year. Any costs associated with changes in the supply system are assumed to be sunk.

Initial training costs consist of the costs associated with training maintenance and operator personnel needed tc man a system. The cost factors used in this analysis are shown in Table VI-12.

Table VI-12

Cost Factors for Initial Training

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Number Personnel Required		Weeks of Training Per Man		Personnel Cost $/Week		Total Initial Training Cost
Config.	ET's	RM's	ET's	RM's	ET's	RM's	(Thous. 1978 $)
V1	3	3	10	0	$315	$306	$ 9.5
V2	3	3	16	1	$315	$306	$16.0
V3	3	6	16	1	$315	$306	$17.0
V4	6	9	16	1	$315	$306	$33.0
V5	6	9	16	1	$315	$306	$33.0

Source: (2)-(3): Chapter II.
(4)-(5): See text.
(6)-(7): Section 3 below.
(8): (2) x (4) x (6) + (3) x (5) x (7).

In columns 2 and 3, the number of personnel (both maintenance [ET's] and operator [RM]) required are shown. [2] Columns 4 and 5 provide the numbers of weeks of training required for ET's and RM's respectively. The factors for the V1 system are based upon the Navy Training Plan for

1/ Personal communication, Mr. S. Lechter, OP-941J, 9/21/77 and Mr. J. Gilbert, NAVELEX.

2/ See Chapter II.

NAVMACS,[1/] while those for V2-V5 are based on COMTRALANT message 061440Z Sept. 1977 subject NAVCAMS (sic) Alpha Plus Maintenance and Operator Training. The weekly personnel cost (columns 6 and 7) are based on the factors discussed in Section 3 below and assume an equal mix of E-4 and E-5 pay grades for both student ET's and RM's. For students, these costs are:[2/]

(($13,105 + $15,684)/2) (1/52) = $277/week

for ET's and

(($12,419 + $15,210)/2) (1/52) = $266/week

for RM's.

In addition to the personnel costs for the students, the cost of the instructors must be included. Of the current 28 ET instructors, 20 are in pay grade E-6 and 8 are in E-7 pay grade.[3/] Based on the personnel cost factors discussed in Section 3 below, the weighted average annual cost of an ET instructor is:

[20($18,306) + 8($22,958)]/28 = $19,635

or

$19,635/52 = $378

weekly.

There are 4 E-6 RM instructors and 2 E-7 RM instructors. Based on the factors in Section 3 below and the same reasoning as above, the weekly cost of an RM instructor is $401.

1/ Enclosure 1 to CNO letter Ser. 992F2/70676, dated 25 March 1975.

2/ See Section 3 below for a discussion of annual personnel cost.

3/ Personal communication, OP 940 LCDR M. Ford.

The current student-instructor ratio for NAVMACS training is about 10.[1/] Therefore we add $38(= .1 x $378) to the weekly personnel cost for ET's and $40 for the weekly personnel costs for RM's to account for instructors. In columns 6 and 7 of Table VI-12 we show these total weekly personnel costs for ET's and RM's respectively.

Finally, in column 8 of Table VI-12, the initial training cost, per installation, is given for each of the five system configurations. The initial training costs associated with upgrades are the differences in the initial training costs between the new and old configurations. For example, the initial training costs for upgrading from a V2 to a V3 system are $1,000 ($17,000 - $16,000). As we discuss below, the cost factors for personnel include some training costs. However, since the extent of NAVMACS training is currently small, the bias caused by this is relatively small. Further, the other costs associated with transportation, etc., have not been included since data at this level of detail was not available for training. This offsets the already small upward bias in the personnel costs.

The final category of investment cost includes miscellaneous investment costs associated with NAVMACS. In this analysis, these costs are composed of communication space reconfiguration designed to accomodate the NAVMACS system. While these could be included under "Installation Costs", we separate the two since any reconfiguration of space is associated with the first installation of a NAVMACS and not with any subsequent replacements. Table VI-13 shows the miscellaneous

1/ Personal communication, LCDR M. Ford OP-940.

investment costs we include in this analysis. We assume that these costs are incurred for any configuration installed. As shown in Table VI-13, all miscellaneous costs are incurred in the "Large Amphibious Warfare" aggregate ship class.

Table VI-13

Miscellaneous Investment Costs
(Thousands FY 1978 Dollars)

Ship Class	Cost	Year Incurred
AGF	$1,056	FY 1980
LPD	$4,224	FY 1979
LPD	$2,112	FY 1980
LPD	$6,336	FY 1981
LPD	$1,056	FY 1982

Source: AMT.

3. Operating Costs

Operating costs include those costs that are incurred annually and that are required for continued system use. The first cost category is system maintenance. As discussed above, this can be subdivided into software maintenance and hardware maintenance. The total cost of software maintenance, as provided in the OPNAV Memorandum of 30 August, 1977, is given in column 1 of Table VI-14 below. These costs apply to the V2 and V3 configurations only.1/ Because we are interested in the costs that would be incurred only if installations took place after October 1, 1977, we must subtract the cost of software maintenance associated with the current installations and add any costs associated with new configurations. We assume that the unavoidable costs are those for software maintenance shown in column 1 of Table VI-13. This is because software maintenance costs depend primarily on the number of configurations and not on the number of ships. Therefore, the costs associated with all alternatives in the cost

1/ Personal communication, Mr. S. Lechter, OP-941J, 9/21/77. Since these costs cannot be separated between V2 and V3, we take them to be the costs associated with current installations.

analysis in which only V2 and V3 configurations are installed are zero.

For scenarios with all five configurations assumed available, we assume that the additional software maintenance costs are equal to those for the V2 and V3 configurations. We assume these costs begin in FY 1983 since responsibility for software maintenance normally reverts to the Navy two years following initial installation.[1/] For scenarios involving only the V1, V2, and V3 configurations, we assume that the avoidable software maintenance costs are one-third that of scenarios with all five configurations, or $300,000 annually beginning in FY 1984. This reflects the fact that there is only one new configuration (V1) instead of three (V1, V4, and V5).

Table VI-14

Software Maintenance
(Thousands FY 1978 Dollars)

Year	(1) Current Cost V2/V3	(2) V1, V4, V5	(3) V1 Only
FY 1978	$640	$ 0	$ 0
FY 1979	700	0	0
FY 1980	720	0	0
FY 1981	720	0	0
FY 1982	820	0	0
FY 1983	920	920	0
FY 1984 and beyond	920	920	300

Source: Column (1): OPNAV Memorandum, 30 August 1977, Subject: NAVMACS Data.
Columns (2)-(3): See text.

The estimated costs for spares and depot support are based on an estimate of $10,000-$16,000 per year for spares and depot support of the V2 configuration.[2/] For this analysis, we have assumed that spares and depot support cost are proportional to equipment cost. Using the equipment cost estimate for a V2 configuration provided in Table VI-11 above, and using $13,000 as the annual spares and depot cost for the V2

1/ Personal communication, Mr. S. Lechter, OP-941J, 9/21/77

2/ Personal communication, Mr. J. Gilbert, NAVELEX

system, we estimate that 7.5% (i.e, $13,000/$174,000) of the original equipment cost provides an estimate of the annual spares and depot cost for all systems. Table VI-15 provides these estimates for configurations V1-V5. The only other configuration for which a spares estimate is available is for the V3, at approximately $20,000 annually.[1/] As can be seen in Table VI-15, this corresponds well to the factor we use and, for consistency, we continue to use the 7.5% factor. Since we are concerned with differential costs, we must subtract the current spares and depot costs for the equipment which the NAVMACS is designed to replace. One estimate of this cost is $8,000-$14,000 annually.[2/] This is not unreasonable given the age of the equipment. We have assumed therefore that $11,000 annually represents the current expenditure for spares and depot maintenance. Subtracting $11,000 from the estimate of spares costs for NAVMACS gives the differential costs associated with NAVMACS equipment. As shown in Table VI-15, the installation of a V1 configuration actually leads to savings in spares and depot support costs.

The next operating cost category is personnel costs. Our development of personnel costs has included an analysis of both billets and total costs. We attempted to determine the extent of the personnel costs (savings) which will accrue to the Navy as a result of the installation of NAVMACS in the fleet. However, we have been unable to obtain current documentation concerning the personnel requirements for the operation and maintenance of the various versions of NAVMACS.

1/ Personal communication, Mr. S. Lechter, OP-941J, 9/21/77.

2/ Personal communication, Mr. J. Gilbert, NAVELEX, 9/21/77.

Table VI-15

Annual Spares and Depot Cost
(Thousands FY 1978 Dollars)

Configuration	Equipment Cost (Thous. 1978 Dollars)	Spares Factor	Annual Spares & Depot Cost	Current Spares	Diff. Spares Cost
V1	100	.075	$ 7.5	$11	$-3.5
V2	174	.075	$13.0	11	2.0
V3	300	.075	$22.5	11	11.5
V4	350	.075	$26.3	11	15.3
V5	898	.075	$67.4	11	56.4

Sources: Equipment cost: Table VI-11
Spares Factor: See text
Annual Spares Cost: Spares Factor multiplied by equipment cost.

Current Spares: Personal communication, Mr. J. Gilbert, NAVELEX
Differential Costs: Annual Spares & Depot cost less current spares

It is our understanding that, as a result of NAVMACS installations, changes will be made to a number of Ship Manning Documents (SMD's) but that these changes have not yet been made. What we have been able to obtain are unofficial estimates of the changes in personnel assignment that will take place. The estimates that we have received from several different sources, however, are in sharp conflict with one another. Thus we feel that, at this time, we must assume that no changes will occur in personnel costs as a result of NAVMACS installations.

Factors for the annual cost of personnel are still required for the fixed, initial, and annual training cost categories. We have relied upon the Navy Billet Cost Model 1/ which is designed to project the total cost to the U.S. Government (not just to the Navy or to the Department of Defense) of maintaining a person in either an established military billet or in a proposed billet. Table VI-16 lists the cost elements which are considered in the determination of billet cost.

The upper part of Table VI-17 presents the latest billet cost data available, that for FY 1977, for two ratings: ET (Electronics Technicians); and RM (Radioman). In the lower part of the table, we show the results of applying a 5% inflation factor (see Section A above) to estimate personnel costs in FY 1978 dollars. These are the costs we use throughout the analysis when dealing with personnel.

1/ B.K. Dynamics, Billet Cost Model Users' Manual TR-3-159, December 1975.

Table VI-16

Cost Factors Included in Billet Cost Model

Base Pay Table Clothing Alws - Initial - Basic - Standard - Special E-7	Messing/Subsistence Alws Overseas Station Allowance Personnel Procurement Proficiency Pay "Q" Allotment
Command and Administration Commissary Death Gratuity Dental Pay Dependent School	Quarters Alws Quarters-single (barracks) Quarters-married (housing) Recreational Facilities Reenlistment/Continuous Pay
Disability Pay Exchange Family Deparation FICA-government contribution Hazardous Duty-aircrew and sub	Responsibility Pay Retirement Pay School Training Sea and Foreign Duty Pay Servicemans Group Life Insurance
Hazardous Duty-non-crew Interest on Deposits Insurance-FHA Housing Medical Costs Medical/Veterinarian Pay	Settlement Costs Severence/Readjustment Pay Travel/Transportation Tuition Aid Unemployment Compensation

Source: B.K. Dynamics, Billet Cost Model Users' Manual, TR-3-159, December 1975.

Table VI-17

Annual Billet Cost - FY 1977 Dollars

Rating	E2	E3	E4	E5	E6	E7	E8	E9
ET	10350	11246	12481	14937	17434	21865	25314	26979
RM	10023	10292	11828	14486	18672	22255	23575	25355

Source: OP-964D

Projected Annual Billet Cost - FY 1978 Dollars

Rating	E2	E3	E4	E5	E6	E7	E8	E9
ET	10868	11808	13105	15684	18306	22958	26580	28328
RM	10524	10807	12419	15210	19606	23368	24754	26623

Source: See text.

Annual training costs consist of those costs required to keep a "pipeline" of trained personnel available for operating and maintaining NAVMACS. In Table VI-18, the factors for annual training cost are shown.

Table VI-18

Cost Factors for Annual Training

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Number Personnel Required		Weeks of Training Per Man		Personnel Cost $/Week			Total Annual Training Cost per Installation (Thousands of Dollars)
Config.	ET's	RM's	ET's	RM's	ET's	RM's	Turnover	
V1	3	3	10	0	$315	$306	1/3	$ 3.2
V2	3	3	16	1	$315	$306	1/3	$ 5.3
V3	3	6	16	1	$315	$306	1/3	$ 5.7
V4	6	9	16	1	$315	$306	1/3	$11.0
V5	6	9	16	1	$315	$306	1/3	$11.0

Source: (2)-(7): Table VI-12.
(8): Personal communication, LCDR M. Ford, OP-940.
(9): (2) x (4) x (6) x (8) + (3) x (5) x (7) x (8).

The first seven columns are identical to those of Table VI-12 above where the initial training costs were computed. In column 8 of Table VI-16, we have used a turnover rate of 1/3. [1] This implies that for every 3 people used for either NAVMACS operation or maintenance, one will not be available in the following year, and replacements must be trained. In column 9, the cost of training these replacements, per installation, is given. Multiplying the per ship cost in column 9 by the number of NAVMACS installed provides an estimate of the total annual training cost.

An additional training cost will be incurred annually: for the training of new instructors.[2] For the training of new instructors, we have assumed that seven ET's and two RM's will be trained annually.[3] For the pay of these instructors, we use the same weighted average used above in Section 1 for fixed training, i.e., an annual cost of $19,635 for ET's and $20,860 for RM's. Assuming 3 weeks of training for each (the same as for the fixed training) the annual cost of training new instructors is estimated to be:

$$(7)(\$19,635/52)(3) + (2)(\$20,860/52)(3) = \$10,300$$

This cost is assumed to be independent of the number of systems installed.

1/ This is the rate used by OP-940 for their planning. Personal communication, LCDR. M. Ford, September 12, 1977.

2/ Costs for the schools themselves are considered to be non-avoidable, i.e., the incremental costs for the schools due to NAVMACS are zero.

3/ Personal communication OP-940, LCDR. M. Ford, with the assumption that two ET instructors would require training even if no installations of NAVMACS occured.

An important benefit the NAVMACS provides is the reduction in messages received over the broadcast that must be printed. Using the differential cost approach, these savings in messages printed appear as a "negative" cost in the analysis since the cost of supplies (paper, ink, etc.) depends directly on the number of messages printed. Estimating these savings requires estimates of the savings per message and the number of messages that will not be printed if NAVMACS is installed on ship.

To estimate the savings per message, we rely on data used by NAVELEX to estimate the consumables costs for NAVMACS.1/ For each of three general types of ship (carriers, V2-type, and V3-type) the following consumable costs are estimated:

- First print cost
- Reproduction cost
- Toner
- Ribbons
- Service Printer

In addition to these costs, NAVELEX associated an average message volume with each of the three types of ship. An average consumable cost per message could thus be obtained by dividing total consumable cost by the average number of messages. This would, however, overstate the savings since this would imply that messages not addressed to the ship would be reproduced in the usual number of copies. Therefore,

1/ Personal communication, Mr. W. Wilcox, NAVELEX.

we use an estimate of the incremental cost associated with a message by calculating the sum of the first print and ribbons costs and dividing by the average number of messages.

The details of this process are shown in Table IV-19. Each of the three general ship types are shown along the top row. The monthly costs associated with the first print and ribbons are given in the first two rows. In row 3, the total consumables costs are shown. In the fourth row, the monthly message volume on which these consumable costs are based are given. These correspond to an average daily load of 1500 for carriers, 100 for V2-type ships and 300 for V3-type ships. In the last row the average cost that could be avoided by not printing a message is shown. From Table VI-19, we see that these savings range from \$.004 to \$.007 per message. The factor for paper cost used by NAVELEX is \$.0033 per sheet for all ship classes, and this is the largest part of the savings. Since the results shown in Table VI-19 indicate that the cost (hence the savings) in ribbons may not be directly related to the number of messages the incremental saving may be only the paper. However, without better information on the actual savings, we will assume that the savings per message is \$.005 per message.1/

1/ We have implicitly assumed that the average message is one page or less. Based on NAVTELCOM data, the average message length is about 1.2 pages. However, this includes headers, which will often be printed even with NAVMACS.

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A COST EFFECTIVENESS ANALYSIS OF THE NAVAL MODULAR AUTOMATED CO--ETC(U)

JAN 78 C E AGNEW, W N LANEN N00014-77-C-0049

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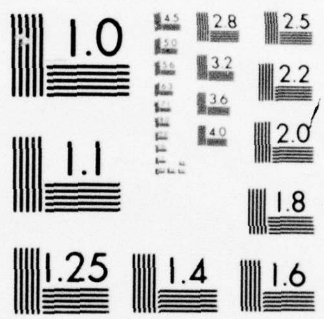

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Table VI-19

Estimating the Savings in Consumable Cost Per Message for Messages Received But Not Printed

Costs & Messages (Monthly)	Type of Ship: Carriers	"V2-Type"	"V3-Type"
First Print	$150	$10	$30
Ribbons	$30	$11	$17
Total Consumables	$180	$21	$47
Average Number of Messages Received	45,000	3,000	9,000
Average Number per Message Not Printed	$.004	$.007	$.005

Source: See text.

Estimating the annual savings in consumables requires that we multiply the $.005 per message by the number of messages that will not be printed. In Chapter IV above, it was estimated that the total broadcast would be 1700 messages daily by the mid-1980's. For each aggregate ship class, the proportion of messages that would not be printed if a NAVMACS was installed was developed in Chapter IV above (Table IV-20). Given these data, total consumable savings can be readily estimated.

Total consumable savings estimates are developed in Table VI-20.

Table VI-20
Consumable Savings

(1) Aggregate Ship Class	(2) Total Messages Broadcast Daily	(3) Proportion Not Printed	(4) Total Not Printed	(5) Savings per Message	(6) Total Annual Consumable Savings (Thous. FY 1978 $)
CV, CVN	1,700	.85	1,445	$.005	2.6
Large CG	1,700	.78	1,326	$.005	2.4
Small CG	1,700	.92	1,564	$.005	2.9
DD, DDG	1,700	.97	1,649	$.005	3.0
FF, FFG	1,700	.98	1,666	$.005	3.0
LCC, LHA, LPD, LPH	1,700	.86	1,462	$.005	2.7
Other Amphibious Warfare	1,700	.97	1,649	$.005	3.0
AD	1,700	.85	1,445	$.005	2.6
AFS	1,700	.92	1,564	$.005	2.9
AS	1,700	.90	1,530	$.005	2.8
Other A	1,700	.94	1,598	$.005	2.9

Source: (2): Chapter IV.
(3): Table IV-20
(4): (2) x (3).
(5): See text.
(6): (4) x (5) x 365.

In column 1, the aggregate ship class is given. In column 2 the total number of messaged broadcast daily developed in Chapter IV is shown. In column 3, proportion of messages not printed is given. This is simply the 1700 messages multiplied by the proportion given in column 3. In column 5, the savings per message ($.005) is shown. Finally, the annual savings are shown in column 7. Note that savings do not depend significantly on either the aggregate ship class or the configuration installed.

The operating costs identified above constitute all relevant costs for the NAVMACS cost analysis. Therefore, "Miscellaneous Operating Costs" are zero.

In the following chapter, the cost factors and assumptions discussed in this chapter are used to estimate the differential cost associated with alternative configurations and installation schedules that may be employed in the implementation of the NAVMACS program.

CHAPTER VII

COST ANALYSIS: RESULTS

This chapter presents the results of the cost analysis for alternative development and installation scenarios for the NAVMACS program. In Section A, the six scenarios which we analyze are described. The results of the individual cost analyses are discussed in Section B. The sensitivity of the results to some of the important assumptions described in the previous chapter are examined in Section C. Finally, the results are compared and summarized in Section D.

A. Scenario Description

In the development of the scenarios whose costs are analyzed below. we consider decisions about the following three questions:

- What configurations will be installed?
- On what aggregate ship classes will the individual configurations be installed?
- What will be the time pattern of installation?

As we discussed in the previous chapter, the baseline scenario is that no new NAVMACS installations are made during or after Fiscal Year 1978. In the baseline scenario therefore, the only ships having a NAVMACS will be those with one currently installed. As the basis for determining the numbers currently in service, we have relied upon the Shipboard Installation Plan dated 15 April 1977. [1] In Table VII-1, we show the breakdown on current installations by aggregate ship class.

1/ Enclosure to Naval Electronic Systems Command Letter 11019/SAL PME106-14/JJB Ser. 370, 26 April 1977.

As shown in the table, 75 ships currently have NAVMACS. This information has been confirmed by OP-941. 1/ In addition to this baseline, there are six other scenarios which we analyze. Each of these are described below. Recall from the previous chapters that all costs, for the scenarios described below, are differences from the baseline.

Table VII-1

Current Installations of NAVMACS

Aggregate Ship Class	Year Installed			Total
	FY 1975	FY 1976	FY 1977	
CV, CVN	1	3	5	9
Large CG	1	1	0	2
Small CG	1	2	5	8
DD, DDG	0	2	10	12
FF, FFG	0	5	14	19
AGF, LCC, LHA, LPD, LPH	2	7	3	12
Small Amphibious	0	3	0	3
AD	0	1	0	1
AFS	1	1	0	2
AS	0	1	0	1
Other A	0	6	0	6
Total	6	32	37	75

Source: Shipboard Installation Plan (PME-106), 15 April 1977.

1/ Personal communication, Mr. S. Lechter, OP-941J, 9/21/77.

1. The AMT Scenario

The first scenario is based on the AMT dated 22 April 1977. [1/] This document provides a detailed schedule of installations. Also included in this document is an indication of the particular configuration to be installed. Unfortunately, the descriptors for the configuration are ambiguous in terms of the "V1, "V2", etc. designations used in this study. For example, the phrase "AN/WSC-3 peripherals" refers to a "V2" configuration. In other places, the installation is termed "NAVMACS B-C-D-E" (recall that these are the older terms for NAVMACS configurations). For this first scenario (called "AMT" for short), we assume that only V2(A+) and V3(B) systems are available. The reason for this is that installation approval for the V1, V4, and V5 configurations has not yet been given.

In the AMT, the majority of ships are given a V2 configuration. The V3 configuration is installed on carriers, large amphibious warships, and AFS's.

Table VII-2 shows the cumulative installation schedule for this scenario. The table shows, for each of the aggregate ship classes, the total number of each configuration installed and (assumed to be) operating each fiscal year. Note that for the aggregate ship class AFS, all installations are upgraded from V2 to V3 configurations. Many V2 configurations are also upgraded to V3 on the large amphibious warfare ships. Note also that under this scenario, there will be 310 NAVMACS installations (including current installations).

1/ Chief of Naval Operations, OP-436, "Amalgamated Military and Technical Improvements," Washington, D.C., April 22, 1977, hereinafter cited as AMT.

Table VII-2

NAVMACS COST-EFFECTIVENESS ANALYSIS
SCENARIO DESCRIPTION

AMT 4/22/77

(NUMBER SYSTEMS IN PLACE)

		1975*	1976*	1977*	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
CV & CVN																						
	V2	1.	4.	9.	9.	9.	9.	9.	9.	9.	9.	9.	9.	9.	9.	9.	9.	9.	9.	9.	9.	9.
	V3	0.	0.	0.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.	4.
LARGE CG																						
	V2	1.	2.	2.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.
	V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
SMALL CG																						
	V2	1.	3.	8.	13.	16.	20.	22.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.
	V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
DD & DDG																						
	V2	0.	2.	12.	28.	52.	71.	75.	82.	82.	82.	82.	82.	82.	82.	82.	82.	82.	82.	82.	82.	82.
	V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
FF & FFG																						
	V2	0.	5.	19.	34.	44.	52.	58.	58.	58.	58.	58.	58.	58.	58.	58.	58.	58.	58.	58.	58.	58.
	V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
LARGE L																						
	V2	2.	9.	12.	13.	15.	10.	6.	7.	5.	5.	5.	5.	5.	5.	5.	5.	5.	5.	5.	5.	5.
	V3	0.	0.	0.	0.	1.	9.	16.	18.	23.	24.	24.	24.	24.	24.	24.	24.	24.	24.	24.	24.	24.

*INSTALLATIONS FOR 1975, 1976, AND 1977 ARE SHOWN FOR INFORMATION ONLY.
ANY COSTS (OR COST-SAVINGS) ARE CONSIDERED SUNK AND ARE NOT INCLUDED IN THE COST ANALYSIS

Table VII-2 (Continued)

NAVMACS COST-EFFECTIVENESS ANALYSIS
SCENARIO DESCRIPTION

AMI 4/22/77

(NUMBER SYSTEMS IN PLACE)

		1975*	1976*	1977*	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
SMALL L																						
	V2	0.	3.	3.	10.	18.	23.	36.	39.	39.	39.	39.	39.	39.	39.	39.	39.	39.	39.	39.	39.	39.
	V3	0.	0.	0.	0.	0.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
AUX AE																						
	V2	0.	1.	1.	2.	5.	5.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.
	V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
AUX AFS																						
	V2	1.	2.	2.	3.	5.	3.	3.	3.	2.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	V3	0.	0.	0.	0.	0.	3.	3.	4.	5.	7.	7.	7.	7.	7.	7.	7.	7.	7.	7.	7.	7.
AUX AS																						
	V2	0.	1.	1.	1.	3.	4.	6.	8.	11.	11.	11.	11.	11.	11.	11.	11.	11.	11.	11.	11.	11.
	V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
OTHER A																						
	V2	0.	6.	6.	8.	15.	16.	24.	32.	32.	32.	32.	38.	38.	38.	38.	38.	38.	38.	38.	38.	38.
	V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
TOTAL																						
	V2	6.	38.	75.	124.	185.	216.	248.	270.	270.	268.	268.	274.	274.	274.	274.	274.	274.	274.	274.	274.	274.
	V3	0.	0.	0.	4.	5.	17.	24.	27.	33.	36.	36.	36.	36.	36.	36.	36.	36.	36.	36.	36.	36.

*INSTALLATIONS FOR 1975, 1976, AND 1977 ARE SHOWN FOR INFORMATION ONLY.
ANY COSTS (OR COST-SAVINGS ARE CONSIDERED SUNK AND ARE NOT INCLUDED IN THE COST ANALYSIS

2. <u>The Full Capability Scenario</u>

The second scenario that we analyze is based on the schedule received from OPNAV. [1/] The schedule is shown in Table VII-3. The configuration to be installed is shown in the left hand column. Upgrades (e.g., from a V2 to a V4 configuration) are shown as V2 → V4. This schedule does not provide installations by aggregate ship class and, in order to provide comparability with the AMT schedule, we have made such an assignment.

In our assignment, we have assumed that the V1 configuration is to be used primarily on ships in the small amphibious warfare and other auxiliary aggregate ship classes. In addition, some V1's are also assigned to the FF, FFG aggregate ship class. The V2 configuration is assigned primarily to the destroyer and frigate aggregate ship classes while a handful (those currently installed on the small amphibious and other auxiliary class) are on ships in other categories. The V3 system is assumed to be primarily installed on small cruisers with the remainder being installed on some destroyers and large amphibious warfare ships. The V3 configuration is also installed on some command and logistic ships while they await upgrading to the V4 or V5 configurations. The V4 configuration is assigned to the AD, AFS, and some of the ships in the AS aggregate ship classes. The V5 configuration is assumed to be installed on carriers, large cruisers, and most large amphibious warfare ships.

These assignments and the cumulative schedule are shown in Table VII-4. Note that in the Full Capability scenario, the total number of installations by the end of the time horizon is 310, which is consistent with the AMT scenario.

1/ Chief of Naval Operations, OP-961E1 Memorandum dated 30 August 1977 - Subject: NAVMACS Data.

Table VII-3

Basic Schedule for the Full Capability Scenario

Configuration	FY 1978	FY 1979	FY 1980	FY 1981	FY 1982	FY 1983	FY 1984
V1	0	0	0	0	28	21	30
V2	36	14	10	10	15	8	9
V3	3	7	6	7	6	6	3
V4	0	0	0	0	5	0	3
V5	0	0	0	6	2	0	0
V2 → V3	0	16	15	7	8	0	0
V2 → V4	0	0	0	0	3	3	0
V2 → V5	0	0	0	5	6	1	0
V3 → V4	0	0	0	0	0	0	4
V3 → V5	0	0	0	0	1	13	7

Source: CNO, OP-961E1 Memorandum dated 30 August 1977 - Subject: NAVMACS Data.

Table VII-4

NAVMACS COST-EFFECTIVENESS ANALYSIS
SCENARIO DESCRIPTION

FULL CAPABILITY

(NUMBER SYSTEMS IN PLACE)

	1975*	1976*	1977*	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
CV & CVN																					
V1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V2	1.	4.	9.	9.	9.	9.	4.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V3	0.	0.	0.	3.	4.	4.	4.	3.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.
V4	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V5	0.	0.	0.	0.	0.	0.	5.	10.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.
LARGE CG																					
V1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V2	1.	2.	2.	3.	3.	3.	3.	3.	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V4	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V5	0.	0.	0.	0.	0.	0.	0.	0.	2.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.
SMALL CG																					
V1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V2	1.	3.	8.	14.	5.	5.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V3	0.	0.	0.	0.	11.	14.	22.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.
V4	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V5	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
DE & DDG																					
V1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V2	0.	2.	12.	28.	28.	30.	36.	40.	48.	56.	56.	56.	56.	56.	56.	56.	56.	56.	56.	56.	56.
V3	0.	0.	0.	0.	6.	8.	10.	21.	25.	26.	26.	26.	26.	26.	26.	26.	26.	26.	26.	26.	26.
V4	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V5	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
FF & FFG																					
V1	0.	0.	0.	0.	0.	0.	0.	3.	7.	10.	10.	10.	10.	10.	10.	10.	10.	10.	10.	10.	10.
V2	0.	5.	19.	29.	34.	40.	43.	47.	47.	48.	48.	48.	48.	48.	48.	48.	48.	48.	48.	48.	48.
V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V4	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V5	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
LARGE L																					
V1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V2	2.	9.	12.	13.	13.	7.	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V3	0.	0.	0.	0.	3.	12.	20.	21.	10.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.
V4	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V5	0.	0.	0.	0.	0.	0.	6.	8.	19.	26.	26.	26.	26.	26.	26.	26.	26.	26.	26.	26.	26.

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Table VII-4 (Continued)

NAVMACS COST-EFFECTIVENESS ANALYSIS
SCENARIO DESCRIPTION

FULL CAPABILITY

(NUMBER SYSTEMS IN PLACE)

	1975*	1976*	1977*	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
SMALL L																					
V1	0.	0.	0.	0.	0.	0.	0.	12.	24.	37.	37.	37.	37.	37.	37.	37.	37.	37.	37.	37.	37.
V2	0.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.
V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V4	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V5	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
AUX AD																					
V1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V2	0.	1.	1.	2.	3.	3.	3.	2.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V4	0.	0.	0.	0.	0.	0.	0.	3.	5.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.
V5	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
AUX AFS																					
V1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V2	1.	2.	2.	3.	2.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V3	0.	0.	0.	0.	2.	4.	4.	4.	4.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V4	0.	0.	0.	0.	0.	0.	0.	2.	2.	7.	7.	7.	7.	7.	7.	7.	7.	7.	7.	7.	7.
V5	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
AUX AS																					
V1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V2	0.	1.	1.	1.	3.	3.	3.	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V3	0.	0.	0.	0.	0.	0.	1.	2.	4.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.
V4	0.	0.	0.	0.	0.	0.	0.	3.	4.	5.	5.	5.	5.	5.	5.	5.	5.	5.	5.	5.	5.
V5	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
OTHER A																					
V1	0.	0.	0.	0.	0.	0.	0.	13.	18.	32.	32.	32.	32.	32.	32.	32.	32.	32.	32.	32.	32.
V2	0.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.
V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V4	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V5	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
TOTAL																					
V1	0.	0.	0.	0.	0.	0.	0.	23.	49.	79.	79.	79.	79.	79.	79.	79.	79.	79.	79.	79.	79.
V2	6.	38.	75.	111.	109.	109.	102.	102.	105.	113.	113.	113.	113.	113.	113.	113.	113.	113.	113.	113.	113.
V3	0.	0.	0.	3.	26.	42.	61.	74.	67.	59.	59.	59.	59.	59.	59.	59.	59.	59.	59.	59.	59.
V4	0.	0.	0.	0.	0.	0.	0.	8.	11.	18.	18.	18.	18.	18.	18.	18.	18.	18.	18.	18.	18.
V5	0.	0.	0.	0.	0.	0.	51.	13.	33.	41.	41.	41.	41.	41.	41.	41.	41.	41.	41.	41.	41.

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3. The V2 Configuration Only Scenario

The third scenario starts with the AMT schedule (scenario 1) but assumes that all installations are of the V2 configuration. Therefore, the total number of installations and the schedule of new installations in each year are the same as for the AMT scenario. The cumulative installation schedule is shown in Table VII-5. The results of this scenario, compared to the AMT (scenario 1), will indicate the additional costs of the decision to introduce the V3 configuration into the fleet.

4. The V1-V3 Scenario

In the fourth scenario, we start with the schedule provided in the Full Capability scenario but assume that only the V1, V2 and V3 configurations will be available. This scenario, when compared to the Full Capability plan (scenario 2), will indicate the additional costs of the V4 and V5 configuration.

In this scenario, the V3 (B) configuration will be installed only on carriers and large cruisers. Ships in the small cruiser, large amphibious warfare, AD, AFS, and AS aggregate ship classes will have V2 configurations. Beginning in FY 1982, ships in all other aggregate ship classes will have V1 configurations installed. Those ships in these smaller aggregate ship classes that have NAVMACS equipment installed prior to FY 1982 will have V2 configurations. There will be no downgrades from V2 to V1 configuration on these ships for two reasons. First, the cost-effective time to downgrade would be at the end of the economic life of the equipment. Since this occurs in the 1990's, the effect of discounting makes the savings that result from downgrading small. The second, and primary reason that we assume that no downgrades will occur is that such a policy appears unrealistic.

Table VII-5

NAVMACS COST-EFFECTIVENESS ANALYSIS
SCENARIO DESCRIPTION

V2 CONFIG. ONLY

(NUMBER SYSTEMS IN PLACE)

	1975*	1976*	1977*	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
CV & CVN																					
V2	1.	4.	9.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.
LARGE CG																					
V2	1.	2.	2.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.
SMALL CG																					
V2	1.	3.	8.	13.	16.	20.	22.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.
DD & DDG																					
V2	0.	2.	12.	28.	52.	71.	75.	82.	82.	82.	82.	82.	82.	82.	82.	82.	82.	82.	82.	82.	82.
FF & FFG																					
V2	0.	5.	19.	34.	44.	52.	58.	58.	58.	58.	58.	58.	58.	58.	58.	58.	58.	58.	58.	58.	58.
LARGE I																					
V2	2.	9.	12.	13.	16.	19.	22.	25.	28.	29.	29.	29.	29.	29.	29.	29.	29.	29.	29.	29.	29.

*INSTALLATIONS FOR 1975, 1976, AND 1977 ARE SHOWN FOR INFORMATION ONLY.
ANY COSTS (OR COST-SAVINGS ARE CONSIDERED SUNK AND ARE NOT INCLUDED IN THE COST ANALYSIS

Table VII-5 (Continued)

NAVMACS COST-EFFECTIVENESS ANALYSIS
SCENARIO DESCRIPTION

V2 CONFIG. ONLY

(NUMBER SYSTEMS IN PLACE)

	1975*	1976*	1977*	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
SMALL 1																					
V2	0.	3.	3.	10.	18.	24.	37.	40.	40.	40.	40.	40.	40.	40.	40.	40.	40.	40.	40.	40.	40.
AUX AD																					
V2	0.	1.	1.	2.	5.	5.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.
AUX APS																					
V2	1.	2.	2.	3.	5.	6.	6.	7.	7.	7.	7.	7.	7.	7.	7.	7.	7.	7.	7.	7.	7.
AUX AS																					
V2	0.	1.	1.	1.	3.	4.	6.	8.	11.	11.	11.	11.	11.	11.	11.	11.	11.	11.	11.	11.	11.
OTHER N																					
V2	0.	6.	6.	8.	15.	16.	24.	32.	32.	32.	32.	38.	38.	38.	38.	38.	38.	38.	38.	38.	38.
TOTAL																					
V2	6.	38.	75.	128.	190.	233.	272.	297.	303.	304.	304.	310.	310.	310.	310.	310.	310.	310.	310.	310.	310.

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ANY COSTS (OR COST-SAVINGS ARE CONSIDERED SUNK AND ARE NOT INCLUDED IN THE COST ANALYSIS

The cumulative schedule by aggregate ship class and configuration is shown in Table VII-6. As shown in Table VII-6, many V2 configurations are installed on small ships simply because the V1 configuration is not available until FY 1982. Again, the total number of ships that will eventually have a NAVMACS installation is 310, based upon the schedule discussed in Section 2 above.

5. <u>The Postponement Scenario</u>

The fifth scenario that we consider is based on the scenario just described. Again, the V1, V2 and V3 configurations are the only configurations assumed to be available. Also, the assignment of configurations to aggregate ship classes is the same as in the previous scenario. In other words, the V3 configuration is installed only on carriers and large cruisers. The V2 configuration is installed on small cruisers, large amphibious warfare ships, AD's, AFS's, and AS's while all other ship classes have the V1 system installed.

The difference in this scenario is that installations of NAVMACS equipment aboard those ships designated to receive V1 configurations are postponed until FY 1982 or after. Thus, for example, no NAVMACS equipment is installed on small auxiliary ships until FY 1982. We do not assume that these postponed installations all occur in FY 1982. Rather, we assume that the number of installations postponed are distributed over the period FY 1982-FY 1984. The scenario is intended to show the effect of termination of V2/V3 installations on smaller ships. These ships, therefore, are not automated until the V1 becomes available. The cumulative

Table VII-6

NAVMACS COST-EFFECTIVENESS ANALYSIS
SCENARIO DESCRIPTION

V1, V2, & V3 ONLY

(NUMBER SYSTEMS IN PLACE)

		1975*	1976*	1977*	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
CV & CVN																						
	V1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	V2	1.	4.	9.	9.	9.	9.	4.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	V3	0.	0.	0.	3.	4.	4.	9.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.
LARGE CG																						
	V1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	V2	1.	2.	2.	3.	3.	3.	3.	3.	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	V3	0.	0.	0.	0.	0.	0.	0.	0.	2.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.
SMALL CG																						
	V1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	V2	1.	3.	8.	14.	16.	19.	22.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.
	V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
DD & DDG																						
	V1	0.	0.	0.	0.	0.	0.	0.	15.	27.	36.	36.	36.	36.	36.	36.	36.	36.	36.	36.	36.	36.
	V2	0.	2.	12.	28.	34.	38.	46.	46.	46.	46.	46.	46.	46.	46.	46.	46.	46.	46.	46.	46.	46.
	V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
FF & FFG																						
	V1	0.	0.	0.	0.	0.	0.	0.	7.	11.	15.	15.	15.	15.	15.	15.	15.	15.	15.	15.	15.	15.
	V2	0.	5.	19.	29.	34.	40.	43.	43.	43.	43.	43.	43.	43.	43.	43.	43.	43.	43.	43.	43.	43.
	V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
LARGE L																						
	V1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	V2	2.	9.	12.	13.	16.	19.	27.	29.	29.	29.	29.	29.	29.	29.	29.	29.	29.	29.	29.	29.	29.
	V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

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ANY COSTS (OR COST-SAVINGS ARE CONSIDERED SUNK AND ARE NOT INCLUDED IN THE COST ANALYSIS

Table VII-6 (Continued)

NAVMACS COST-EFFECTIVENESS ANALYSIS
SCENARIO DESCRIPTION

V1, V2, & V3 ONLY

(NUMBER SYSTEMS IN PLACE)

	1975*	1976*	1977*	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
SMALL L																					
V1	0.	0.	0.	0.	0.	0.	0.	12.	24.	37.	37.	37.	37.	37.	37.	37.	37.	37.	37.	37.	37.
V2	0.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.
V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
AUX AE																					
V1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V2	0.	1.	1.	2.	3.	3.	3.	5.	5.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.
V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
AUX AFS																					
V1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V2	1.	2.	2.	3.	4.	4.	4.	6.	6.	7.	7.	7.	7.	7.	7.	7.	7.	7.	7.	7.	7.
V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
AUX AS																					
V1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V2	0.	1.	1.	1.	3.	3.	4.	6.	8.	11.	11.	11.	11.	11.	11.	11.	11.	11.	11.	11.	11.
V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
OTHER A																					
V1	0.	0.	0.	0.	0.	0.	0.	13.	18.	32.	32.	32.	32.	32.	32.	32.	32.	32.	32.	32.	32.
V2	0.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.
V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
TOTAL																					
V1	0.	0.	0.	0.	0.	0.	0.	47.	80.	120.	120.	120.	120.	120.	120.	120.	120.	120.	120.	120.	120.
V2	6.	38.	75.	111.	131.	147.	165.	170.	170.	174.	174.	174.	174.	174.	174.	174.	174.	174.	174.	174.	174.
V3	0.	0.	0.	3.	4.	4.	9.	13.	15.	16.	16.	16.	16.	16.	16.	16.	16.	16.	16.	16.	16.

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schedule of NAVMACS installations under the postponement scenario is shown in Table VII-7.

6. The Large Ships Only Scenario

In this final scenario, we take the schedule of the Full Capability scenario (see Section 2 above), but assume that only large ships (carriers [with the exception of the CVT], cruisers [large and small], large amphibious warfare ships, AD's, AFS's, and AS's) are provided with NAVMACS equipment. Of these classes, the carriers and large cruisers are the only ships to receive the V3 configuration. The V1, V4 and V5 are not developed. This scenario is intended to indicate the costs of a program that automates only the larger ships.

The cumulative installation schedule is shown in Table VII-8. For the "large" ship classes (again with the exception of the CVT), this is the same as the V1-V3 only scenario whose installation schedule is shown above in Table VII-6. From Table VII-8, the number of ships that will eventually be provided with NAVMACS capability is 131 or 179 fewer than under the other scenarios.

7. Summary of Scenarios

Recall that we began this chapter with a specification of the decisions that make up an individual scenario. These are:

- what configurations will be installed,
- on what aggregate ship classes will the individual configurations be installed, and
- what will be the installation schedule.

We can use this same framework to summarize and compare the alternative scenarios we have analyzed.

Table VII-7

NAVMACS COST-EFFECTIVENESS ANALYSIS
SCENARIO DESCRIPTION

POSTPONE INSTALLATIONS

(NUMBER SYSTEMS IN PLACE)

		1975*	1976*	1977*	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
CV & CVN																						
	V1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	V2	1.	4.	9.	9.	9.	9.	4.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	V3	0.	0.	0.	3.	4.	4.	9.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.	13.
LARGE CG																						
	V1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	V2	1.	2.	2.	3.	3.	3.	3.	3.	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	V3	0.	0.	0.	0.	0.	0.	0.	0.	2.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.
SMALL CG																						
	V1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	V2	1.	3.	8.	14.	16.	19.	22.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.
	V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
DD & DDG																						
	V1	0.	0.	0.	0.	0.	0.	0.	25.	47.	70.	70.	70.	70.	70.	70.	70.	70.	70.	70.	70.	70.
	V2	0.	2.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.
	V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
FF & FFG																						
	V1	0.	0.	0.	0.	0.	0.	0.	13.	26.	39.	39.	39.	39.	39.	39.	39.	39.	39.	39.	39.	39.
	V2	0.	5.	19.	19.	19.	19.	19.	19.	19.	19.	19.	19.	19.	19.	19.	19.	19.	19.	19.	19.	19.
	V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
LARGE I																						
	V1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	V2	2.	9.	12.	13.	16.	19.	27.	29.	29.	29.	29.	29.	29.	29.	29.	29.	29.	29.	29.	29.	29.
	V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

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Table VII-7 (Continued)

NAVMACS COST-EFFECTIVENESS ANALYSIS
SCENARIO DESCRIPTION

POSTPONE INSTALLATIONS

(NUMBER SYSTEMS IN PLACE)

	1975*	1976*	1977*	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
SMALL L																					
V1	0.	0.	0.	0.	0.	0.	0.	12.	24.	37.	37.	37.	37.	37.	37.	37.	37.	37.	37.	37.	37.
V2	0.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.
V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
AUX AD																					
V1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V2	0.	1.	1.	2.	3.	3.	3.	5.	5.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.
V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
AUX AFS																					
V1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V2	1.	2.	2.	3.	4.	4.	4.	6.	6.	7.	7.	7.	7.	7.	7.	7.	7.	7.	7.	7.	7.
V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
AUX AS																					
V1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
V2	0.	1.	1.	1.	3.	3.	4.	6.	8.	11.	11.	11.	11.	11.	11.	11.	11.	11.	11.	11.	11.
V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
OTHER A																					
V1	0.	0.	0.	0.	0.	0.	0.	13.	18.	32.	32.	32.	32.	32.	32.	32.	32.	32.	32.	32.	32.
V2	0.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.
V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
TOTAL																					
V1	0.	0.	0.	0.	0.	0.	0.	63.	115.	178.	178.	178.	178.	178.	178.	178.	178.	178.	178.	178.	178.
V2	6.	38.	75.	85.	94.	100.	107.	112.	112.	116.	116.	116.	116.	116.	116.	116.	116.	116.	116.	116.	116.
V3	0.	0.	0.	3.	4.	4.	9.	13.	15.	16.	16.	16.	16.	16.	16.	16.	16.	16.	16.	16.	16.

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Table VII-8

NAVMACS COST-EFFECTIVENESS ANALYSIS
SCENARIO DESCRIPTION

LARGE SHIPS ONLY

(NUMBER SYSTEMS IN PLACE)

		1975*	1976*	1977*	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
CV & CVN																						
	V2	1.	4.	9.	9.	9.	9.	4.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	V3	0.	0.	0.	3.	3.	3.	8.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.
LARGE CG																						
	V2	1.	2.	2.	3.	3.	3.	3.	3.	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
	V3	0.	0.	0.	0.	0.	0.	0.	0.	2.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.
SMALL CG																						
	V2	1.	3.	8.	14.	16.	19.	22.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.	23.
	V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
DE & DDG																						
	V2	0.	2.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.	12.
	V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
FF & FFG																						
	V2	0.	5.	19.	19.	19.	19.	19.	19.	19.	19.	19.	19.	19.	19.	19.	19.	19.	19.	19.	19.	19.
	V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
LARGE L																						
	V2	2.	9.	12.	13.	16.	19.	27.	29.	29.	29.	29.	29.	29.	29.	29.	29.	29.	29.	29.	29.	29.
	V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

*INSTALLATIONS FOR 1975, 1976, AND 1977 ARE SHOWN FOR INFORMATION ONLY.
ANY COSTS (OR COST-SAVINGS ARE CONSIDERED SUNK AND ARE NOT INCLUDED IN THE COST ANALYSIS

Table VII-8 (Continued)

NAVMACS COST-EFFECTIVENESS ANALYSIS
SCENARIO DESCRIPTION

LARGE SHIPS ONLY

(NUMBER SYSTEMS IN PLACE)

		1975*	1976*	1977*	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
SMALL L																						
	V2	0.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.	3.
	V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
AUX AD																						
	V2	0.	1.	1.	2.	3.	3.	3.	5.	5.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.
	V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
AUX AFS																						
	V2	1.	2.	2.	3.	4.	4.	4.	6.	6.	7.	7.	7.	7.	7.	7.	7.	7.	7.	7.	7.	7.
	V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
AUX AS																						
	V2	0.	1.	1.	1.	3.	3.	4.	6.	8.	11.	11.	11.	11.	11.	11.	11.	11.	11.	11.	11.	11.
	V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
OTHER A																						
	V2	0.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.	6.
	V3	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
TOTAL																						
	V2	6.	38.	75.	85.	94.	100.	107.	112.	112.	116.	116.	116.	116.	116.	116.	116.	116.	116.	116.	116.	116.
	V3	0.	0.	0.	3.	3.	3.	8.	12.	14.	15.	15.	15.	15.	15.	15.	15.	15.	15.	15.	15.	15.

*INSTALLATIONS FOR 1975, 1976, AND 1977 ARE SHOWN FOR INFORMATION ONLY.
ANY COSTS (OR COST-SAVINGS ARE CONSIDERED SUNK AND ARE NOT INCLUDED IN THE COST ANALYSIS

In Table VII-9, the configurations to be installed under each scenario are shown. We have included "none" as a configuration under the large ships scenario to emphasize that in this scenario, some ships do not receive NAVMACS capability. Only in the Full Capability scenario (scenario 2) are all five configurations installed. Scenarios 4 and 5 do not differ in the configurations installed.

Table VII-9

Configurations Installed Under Alternative Scenarios

Scenario	Description	Configurations Installed
1	AMT 4/77	V2, V3
2	Full Capability	V1-V5
3	V2 Only	V2
4	V1-V3 Only	V1, V2, V3
5	Postponement	V1, V2, V3
6	Large Ships Only	None, V2, V3

As is evident from Table VII-9, our different scenarios do not, strictly speaking, provide the same capability. However, based on the analyses in Chapter V, we have found that the V2 and V3 configurations are adequate for all aggregate ship classes, and may provide more capability than is needed on the smaller ships. Moreover, the V4 and V5 configurations may not provide a substantial additional improvement in

capability. Thus, all scenarios except the last one (Large Ships Only) appear to provide adequate automated capability to all ships. Thus, the scenarios may be regarded as representing various possible ways in which different levels of automated message processing capability can be installed in the fleet.

In Table VII-10, the pairing of aggregate ship class with NAVMACS configuration is given. In Scenario 3 (V2 only), all ships receive a V2 configuration. The AMT scenario, scenario 1, shows the assignment of configurations to aggregate ship class based upon information in the AMT itself. Note that some aggregate ship classes have more than one configuration.

In the full capability scenario (scenario 2), the assignment of configurations to aggregate ship classes was somewhat arbitrary since a detailed schedule was not available. However, as can be seen in Table VII-10, large ships with command capability (carriers, large cruisers, and some large amphibious warfare ships) receive the V5 system while large logistics ships (AD's, AFS's, AS's) are assigned the V4 configuration. The V1 configuration is installed mainly on the small auxiliaries and small amphibious warfare ships. Some frigates are also shown with V1's. The analyses are broken down into aggregate ship classes to provide a link with the traffic and effectiveness analyses of previous chapters and for comparison with the cost analysis for the AMT schedule.

In scenarios 4, 5, and 6, V3 configurations are installed on carriers and large cruisers. In scenarios 4 and 5, V1 configurations are installed on destroyers, frigates, small amphibious warfare ships and small auxiliaries. The V2 configuration is installed on the other aggregate ship classes.

Table VII-10

Configuration-Ship Class Pairing When All Installations Complete

Aggregate Ship Class	Scenario 1 AMT 4/77	Scenario 2 Full Capability	Scenario 3 V2 Only	Scenario 4 V1 - V3 Only	Scenario 5 V1 - V3 Only Postponement	Scenario 6 Large Ships Only
CV, CVN	V2, V3	V5	V2	V3	V3	V3
Large CG	V2	V5	V2	V3	V3	V3
Small CG	V2	V3	V2	V2	V2	V2
DD, DDG	V2	V2, V3	V2	V1, V2	V1, V2*	NONE**
FF, FFG	V2	V1, V2	V2	V1, V2	V1, V2*	NONE**
LCC, LHA, LPD, LPH	V2, V3	V3, V5	V2	V2	V2	V2
Small Amphibious	V2, V3	V1, V2*	V2	V1, V2*	V1, V2*	NONE**
AD	V2	V4	V2	V2	V2	V2
AFS	V3	V4	V2	V2	V2	V2
AS	V2	V3, V4	V2	V2	V2	V2
Other A	V2	V1, V2*	V2	V1, V2*	V1, V2*	NONE**

* Current installations only.

** Except for current installations.

The final decision reflected in the scenarios concerns the schedule of installations of the equipment. In Table VII-11, the schedule for each of the scenarios is shown. We have shown separately new installations (i. e., installations on ships with no NAVMACS equipment) and upgrades (e. g., replacing a V2 configuration with a V3 configuration). In the AMT scenario, there are 235 new installations and 20 upgrades (all are upgrades of V2 configurations). Given that there are 75 currently installed NAVMACS, we see that the total number of ships with NAVMACS capability will be 310 (=235 + 75). In scenario 3 (V2 only), there will again be 235 new installations with no upgrades.

The full capability scenario (scenario 2) also has 235 new installations giving 310 ships eventual NAVMACS capability. However, there are considerably more upgrades (89) with this scenario since the V4 and V5 configurations will eventually be available. In scenario 4, the number of new installations is the same as under the full capability scenario. The number of upgrades is considerably fewer since only the V1-V3 configurations are assumed to be available.

Under the fifth scenario, the total number of new installations and upgrades is the same as under the V1-V3 scenario, but the timing is different. With the V1-V3 scenario, there are 99 new installations in the period FY 1978-FY 1981 while under the postponement scenario there are only 51. Finally, in the Large Ships scenario, there are only 68 new installations and 12 upgrades reflecting the decision not to install NAVMACS equipment on small ships.

Table VII-11

Installation Schedule for Alternative Scenarios

	1978	1979	1980	1981	1982	1983	1984	1985	1986	After 1986	Total (FY 1978 and Beyond)
Scenario 1:											
New Inst.	53	62	43	39	25	6	1	0	6	0	235
Upgrades	0	0	9	5	1	3	2	0	0	0	20
Total Inst.	53	62	52	44	26	9	3	0	6	0	255
Scenario 2:											
New Inst.	39	21	16	23	56	35	45	0	0	0	235
Upgrades	0	16	15	12	18	17	11	0	0	0	89
Total Inst.	39	37	31	35	74	52	56	0	0	0	324
Scenario 3:											
New Inst.	53	62	43	39	25	6	1	0	6	0	235
Upgrades	0	0	0	0	0	0	0	0	0	0	0
Total Inst.	53	62	43	39	25	6	1	0	6	0	235
Scenario 4:											
New Inst.	39	21	16	23	56	35	45	0	0	0	235
Upgrades	0	0	0	5	6	1	0	0	0	0	12
Total Inst.	39	21	16	28	62	36	45	0	0	0	247
Scenario 5:											
New Inst.	13	10	6	6	70	60	70	0	0	0	235
Upgrades	0	0	0	5	6	1	0	0	0	0	12
Total Inst.	13	10	6	11	76	61	70	0	0	0	247
Scenario 6:											
New Inst.	13	9	6	6	7	8	7	0	0	0	56
Upgrades	0	0	0	5	6	1	0	0	0	0	12
Total Inst.	13	9	6	11	13	9	7	0	0	0	68

B. Results of Scenario Cost Analyses

In this section, we present the results of the cost analyses for the individual scenarios described in the previous section. Results for each scenario and summary results by aggregate ship class are discussed.

1. The AMT Scenario

Recall that the AMT scenario is based upon the AMT of April 22, 1977 and shows installations of V2 and V3 configurations on a total of 310 ships by FY 1986. The overwhelming number of these installations are of the V2 configuration (274 V2's compared to 36 V3's). The total cost of this scenario by year and cost category is shown in Table VII-12.[1/]

While the results in that table are fairly self-explanatory, there are several interesting items. First, RDT&E costs consist solely of the $900,000 for the V3 systems that are required for schools. This is a result of the fact that in the AMT scenario, the only configurations assumed to be installed are the V2 and V3 on which almost all RDT&E (as we have defined it in Chapter VI) has been completed. Second, the costs peak in FY 1979 ($25 million) with a second, lower, peak in the mid-1990's. The first peak is due, of course, to the fact that more new systems are installed in FY 1979 (62) than in any other year. The later peak is a result of using an economic life of 15 years. Beginning in FY 1990, replacement systems cost must be included for those systems whose economic life is ending. Third, the negative investment cost is also a reflection of the economic life assumption in which the scenario is "credited" with the value of the remaining life for the installed systems.

1/ Individual rows and columns may not add because of rounding. This is true for all subsequent tables as well.

Table VII-12

NAVMACS COST-EFFECTIVENESS ANALYSIS
SCENARIO: AMT 4/22/77

(ALL COSTS IN THOUS. FY78$)

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
RDT&E COSTS										
SOFTWARE DEVEL.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INSTR. TRNG.	900.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TEST & EVAL.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL RDT&E	900.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INVESTMENT COSTS										
EQUIPMENT	9726.0	10914.0	8994.0	7668.0	4728.0	1800.0	552.0	0.0	1044.0	0.0
INSTALLATION										
LABOR	6833.6	7408.1	9324.2	6201.8	3021.2	2390.3	735.2	0.0	215.2	0.0
MATERIAL	1117.0	1293.0	1589.0	1356.0	663.0	509.0	157.0	0.0	108.0	0.0
FIXED LOGISTIC										
INIT SPARES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OTHER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INITIAL TRAINING	852.0	993.0	700.0	631.0	403.0	102.0	19.0	0.0	96.0	0.0
MISC. INVEST.	0.0	4224.0	3168.0	6336.0	1056.0	0.0	0.0	0.0	0.0	0.0
TOTAL INVESTMENT	18528.6	24832.1	23775.2	22192.8	9871.1	4801.3	1463.2	0.0	1463.2	0.0
OPERATING COSTS										
ANNUAL MAINT.										
SOFTWARE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SPARES/DEPOT	144.0	277.5	477.5	622.0	700.5	769.5	800.0	800.0	812.0	812.0
SHIP PERSONNEL										
ET BILLETS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RM BILLETS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SHIP PERS COSTS										
ET	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL TRNG.	292.8	621.8	854.5	1064.0	1197.7	1231.9	1238.4	1238.4	1270.2	1270.2
SUPPLIES	-155.3	-337.6	-464.9	-579.2	-651.9	-668.4	-671.1	-671.1	-688.5	-688.5
MISC. OPER.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL OPERATIONS	281.5	561.7	867.1	1106.8	1246.3	1333.0	1367.3	1367.3	1393.7	1393.7
TOTAL ANNUAL COST	19710.1	25393.8	24642.3	23299.6	11117.4	6134.3	2830.5	1367.3	2856.9	1393.7

Table VII-12 (Continued)

NAVMACS COST-EFFECTIVENESS ANALYSIS
SCENARIO: AMT 4/22/77

(ALL COSTS IN THOUS. FY78$)

	1988	1989	1990	1991	1992	1993	1994	1995	1996	TOTAL
RDT&E COSTS										
SOFTWARE DEVEL.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INSTR. TRNG.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	900.0
TEST & EVAL.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL RDT&E	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	900.0
INVESTMENT COSTS										
EQUIPMENT	0.0	0.0	522.0	4176.0	5916.0	9552.0	10566.0	10386.0	-39234.5	47309.5
INSTALLATION										
LABOR	0.0	0.0	394.1	2370.8	4980.8	6786.4	7313.7	9807.1	0.0	67782.3
MATERIAL	0.0	0.0	65.0	513.0	724.0	1099.0	1257.0	1728.0	0.0	12178.0
FIXED LOGISTIC										
INIT SPARES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OTHER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INITIAL TRAINING	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3796.0
MISC. INVEST.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14784.0
TOTAL INVESTMENT	0.0	0.0	981.1	7059.8	11620.8	17437.4	19136.7	21921.1	-39234.5	145849.4
OPERATING COSTS										
ANNUAL MAINT.										
SOFTWARE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SPARES/DEPOT	812.0	812.0	824.0	888.0	962.0	962.0	962.0	962.0	0.0	13399.0
SHIP PERSONNEL										
ET BILLETS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RM BILLETS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SHIP PERS COSTS										
ET	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL ENG.	1270.2	1270.2	1302.0	1471.6	1667.7	1667.7	1667.7	1667.7	0.0	22264.7
SUPPLIES	-688.5	-688.5	-704.7	-755.3	-902.9	-902.9	-902.9	-902.9	0.0	-12065.1
MISC. OPER.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL OPERATIONS	1393.7	1393.7	1421.3	1564.3	1726.8	1726.8	1726.8	1726.8	0.0	23598.5
TOTAL ANNUAL COST	1393.7	1393.7	2402.4	8624.1	13347.6	19164.2	20863.5	23647.9	-39234.5	170347.8

TOTAL DISCOUNTED COST (TO 1978): $ 110845.8

As shown in Table VII-12, the total discounted costs for this scenario are $111 million over the period FY 1978-FY 1995. This represents an average (discounted) cost per installation of about $350,000.[1/]

In Table VII-13, the results of the cost analysis for the AMT scenario are broken down by aggregate ship class. As might be expected, the total discounted costs across ship class vary with the number of ships (a reflection of the number of systems installed). The one exception to this is the aggregate ship class consisting of LCC's, LHA's, LPD's, and LPH's. This is because there are a significant number of ships that fall into this class (29) and 23 of the ships have a V3 configuration installed.

2. The Full Capability Scenario

The second scenario we have analyzed assumes that all five configurations (V1-V5) are installed. Table VII-14 presents the results for this scenario. The total discounted cost for this scenario is $148 million or $37 million more than the AMT scenario. This represents an average cost per equipped ship of about $500,000. In addition to the obviously higher equipment cost, the reasons for this higher cost include the greater impact of RDT&E costs in this scenario, the impace of the software maintenance costs that must be borne in this scenario, and the greater spares and annual training costs

1/ This is averaged over all installations, including those currently in place.

Table VII-13

Total Discounted Avoidable Cost By Aggregate Ship Class
AMT Scenario

(All Costs in Thousands of FY 1978 Dollars)

Aggregate Ship Class	Total Discounted Avoidable Cost
CV, CVN	3.1
Large Cruisers	0.5
Small Cruisers	7.1
DD, DDG	27.7
FF, FFG	16.8
LCC, LHA, LPD, LPH	28.7
Small Amphibious Warships	12.0
AD	1.4
AFS	3.3
AS	2.4
Other Auxiliaries	6.9
Residual *	1.0
Total	110.8

* Includes RDT&E, Software Maintenance and Annual Instructor Training.

Note: Total may not add due to rounding.

Table VII-14

NAVMACS COST-EFFECTIVENESS ANALYSIS
SCENARIO: FULL CAPABILITY

(ALL COSTS IN THOUS. FY78$)

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
RDT&E COSTS										
SOFTWARE DEVEL.	1000.0	0.0	2500.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INSTR. TRNG.	900.0	0.0	600.0	2538.0	0.0	0.0	0.0	0.0	0.0	0.0
TEST & EVAL.	0.0	0.0	100.0	200.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL RDT&E	1900.0	0.0	3200.0	2738.0	0.0	0.0	0.0	0.0	0.0	0.0
INVESTMENT COSTS										
EQUIPMENT	7164.0	6552.0	4800.0	14230.0	15656.0	14652.0	11418.0	0.0	0.0	0.0
INSTALLATION										
LABOR	5526.5	6477.7	6213.2	9614.1	8463.0	4895.7	4649.5	0.0	0.0	0.0
MATERIAL	772.0	989.0	1060.0	1689.0	1762.0	1074.0	1189.0	0.0	0.0	0.0
FIXED LOGISTIC										
INIT SPARES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OTHER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INITIAL TRAINING	627.0	359.0	272.0	574.0	992.0	722.5	772.0	0.0	0.0	0.0
MISC. INVEST.	0.0	4224.0	3168.0	6336.0	1056.0	0.0	0.0	0.0	0.0	0.0
TOTAL INVESTMENT	14089.5	18601.7	15513.2	32443.1	27919.0	21344.1	18028.4	0.0	0.0	0.0
OPERATING COSTS										
ANNUAL MAINT.										
SOFTWARE	0.0	0.0	0.0	0.0	0.0	920.0	920.0	920.0	920.0	920.0
SPARES/DEPOT	106.5	367.0	551.0	1375.9	1944.6	2688.5	3065.8	3065.8	3065.8	3065.8
SHIP PERSONNEL										
ET BILLETS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RM BILLETS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SHIP PERS COSTS										
ET	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL TRNG.	218.2	338.7	429.9	622.1	950.8	1192.0	1449.8	1449.8	1449.8	1449.8
SUPPLIES	-113.8	-174.4	-221.2	-287.3	-451.9	-556.0	-688.5	-688.5	-688.5	-688.5
MISC. OPER.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL OPERATIONS	210.9	531.3	759.7	1710.7	2443.5	4244.5	4747.1	4747.1	4747.1	4747.1
TOTAL ANNUAL COST	16200.4	19133.0	19472.9	36891.8	30362.5	25588.6	22775.5	4747.1	4747.1	4747.1

Table VII-14 (Continued)

NAVMACS COST-EFFECTIVENESS ANALYSIS
SCENARIO: FULL CAPABILITY

(ALL COSTS IN THOUS. FY78$)

	1988	1989	1990	1991	1992	1993	1994	1995	1996	TOTAL
RDT&E COSTS										
SOFTWARE LEVEL.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3500.0
INSTR. TRNG.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4038.0
TEST & EVAL.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	300.0
TOTAL RDT&E	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7838.0
INVESTMENT COSTS										
EQUIPMENT	0.0	0.0	0.0	2436.0	2436.0	3828.0	7614.0	5640.0	-31742.7	64683.3
INSTALLATION										
LABOR	0.0	0.0	0.0	1198.1	2046.2	3260.9	4866.5	5356.5	0.0	62567.8
MATERIAL	0.0	0.0	0.0	257.0	294.0	426.0	634.0	925.0	0.0	11111.0
FIXED LOGISTIC										
INIT SPARES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OTHER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INITIAL TRAINING	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4308.5
MISC. INVEST.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14784.0
TOTAL INVESTMENT	0.0	0.0	0.0	3931.1	4776.2	7514.9	13114.5	11921.5	-31742.7	157454.3
OPERATING COSTS										
ANNUAL MAINT.										
SOFTWARE	920.0	920.0	920.0	920.0	920.0	920.0	920.0	920.0	0.0	11960.0
SPARES/DEPOT	3065.8	3065.8	3077.8	3141.8	3215.8	3215.8	3215.8	3215.8	0.0	44511.1
SHIP PERSONNEL										
ET BILLETS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RM BILLETS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SHIP PERS COSTS										
ET	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL TRNG.	1449.8	1449.8	1481.6	1651.2	1847.3	1847.3	1847.3	1847.3	0.0	22972.5
SUPPLIES	-688.5	-688.5	-704.7	-795.3	-902.9	-902.9	-902.9	-902.9	0.0	-11047.2
MISC. OPER.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL OPERATIONS	4747.1	4747.1	4774.7	4917.7	5080.2	5080.2	5080.2	5080.2	0.0	68396.3
TOTAL ANNUAL COST	4747.1	4747.1	4774.7	8848.8	9856.4	12595.1	18194.7	17001.7	-31742.7	233688.4

TOTAL DISCOUNTED COST (TO 1978) : $ 148354.4

that are incurred with the installation of all five configurations. The reasons for the additional costs are clear: more complex (expensive) configurations are being used in place of less expensive equipment. This becomes particularly clear when we consider the discounted total costs by ship class as shown in Table VII-15. Recall that in the AMT scenario that the larger aggregate ship classes 1/ represented 42 percent of the total discounted costs while in this scenario they represent 61 percent of the total cost.

Peak costs occur in FY 1981 rather than in FY 1979 as in the AMT scenario. The reason for this is first, that the installation schedule in the Full Capacity scenario is spread out relative to the AMT schedule. Second, the new configurations (V1, V4, and V5) are first available in FY 1981 and FY 1982.

3. The V2 Only Scenario

The V2 Only scenario uses the schedule of implementation in the AMT scenario but assumes that all installations are of the V2 configuration. The costs associated with this scenario are shown in Table VII-16. As shown in that table, the total discounted costs for this scenario are $95 million or about $300,000 per ship. The reason for the lower costs in this scenario compared with the AMT scenario are obvious. By not

1/ Carriers, cruisers (large and small), LCC's, LHA's, LPD's, LPH's AD's, AFS's, and AS's.

Table VII-15

Total Discounted Avoidable Cost By Aggregate Ship Class
Full Capability Scenario
(All Costs in Thousands of FY 1978 Dollars)

Aggregate Ship Class	Total Discounted Avoidable Cost
CV, CVN	13.0
Large Cruisers	2.6
Small Cruisers	13.1
DD, DDG	28.4
FF, FFG	13.7
LCC, LHA, LPD, LPH	48.4
Small Amphibious Warships	4.5
AD	2.4
AFS	4.0
AS	4.0
Other Auxiliaries	2.9
Residual *	11.3
Total	148.3

* Includes RDT&E, Software Maintenance and Annual Instructor Training.

Note: Total may not add due to rounding.

installing the V3 configuration, the higher investment and operating costs associated with the larger configuration are avoided. The difference in the present value of cost compared to the AMT scenario, 16 million dollars, indicates the additional cost of V3 capability under present planning.

In Table VII-17, the total discounted costs by aggregate ship class are shown. These costs are equal to, or less than, the corresponding costs for the AMT scenario in every class.

4. The V1-V3 Scenario

In this scenario, the installation schedule of the Full Capability scenario is used but the only configurations that are installed are the and V3. The results of the cost analysis for this scenario are shown in Table VII-18. The total discounted costs associated with this scenario are $79 million, about one-half the cost of the Full Capability scenario. This difference is an indication of the incremental cost of having V4 and V5 capability on large ships. In this scenario, the average discounted cost per ship is about $250,000. The lower costs result from savings in all three cost categories: RDT&E, investment and operating. Because the scheduling is the same as under the Full Capability scenario, the peak costs occur in FY 1982. One interesting fact in this scenario is that because of the large number of V1 systems installed, there are savings in spare parts

Table VII-16

NAVMACS COST-EFFECTIVENESS ANALYSIS
SCENARIO: V2 CONFIG. ONLY

(ALL COSTS IN THOUS. FY78$)

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
RDT&E COSTS										
SOFTWARE DEVEL.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INSTR. TRNG.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TEST & EVAL.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL RDT&E	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INVESTMENT COSTS										
EQUIPMENT	9222.0	10788.0	7482.0	6786.0	4350.0	1044.0	174.0	0.0	1044.0	0.0
INSTALLATION										
LABOR	6833.6	7030.1	5586.3	3556.3	2117.1	352.5	60.9	0.0	215.2	0.0
MATERIAL	1117.0	1221.0	866.0	852.0	484.0	114.0	15.0	0.0	108.0	0.0
FIXED LOGISTIC										
INIT SPARES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OTHER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INITIAL TRAINING	848.0	992.0	698.0	624.0	400.0	96.0	16.0	0.0	96.0	0.0
MISC. INVEST.	0.0	4224.0	3168.0	6336.0	1056.0	0.0	0.0	0.0	0.0	0.0
TOTAL INVESTMENT	18020.6	24255.1	17790.3	18154.3	8407.1	1606.5	265.9	0.0	1463.2	0.0
OPERATING COSTS										
ANNUAL MAINT.										
SOFTWARE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SPARES/DEPOT	106.0	230.0	316.0	394.0	444.0	456.0	458.0	458.0	470.0	470.0
SHIP PERSONNEL										
ET BILLETS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RM BILLETS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SHIP PERS COSTS										
ET	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL TRNG.	291.2	619.8	847.7	1054.4	1186.9	1218.7	1224.0	1224.0	1255.8	1255.8
SUPPLIES	-155.3	-337.6	-464.9	-579.2	-651.9	-668.4	-671.1	-671.1	-688.5	-688.5
MISC. OPER.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL OPERATIONS	241.9	512.2	698.6	869.2	979.0	1006.3	1010.9	1010.9	1037.3	1037.3
TOTAL ANNUAL COST	18262.5	24767.3	18489.1	19023.5	9386.1	2612.8	1276.8	1010.9	2500.5	1037.3

Table VII-16 (Continued)

NAVMACS COST-EFFECTIVENESS ANALYSIS
SCENARIO: V2 CONFIG. ONLY

(ALL COSTS IN THOUS. FY78$)

	1988	1989	1990	1991	1992	1993	1994	1995	1996	TOTAL
RDT&E COSTS										
SOFTWARE DEVEL.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INSTR. TRNG.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TEST & EVAL.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL RDT&E	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INVESTMENT COSTS										
EQUIPMENT	0.0	0.0	1044.0	5568.0	6438.0	9222.0	10788.0	7482.0	-37704.2	43727.8
INSTALLATION										
LABOR	0.0	0.0	563.1	2844.3	5163.5	6833.6	7030.1	5586.3	0.0	53773.0
MATERIAL	0.0	0.0	113.0	636.0	769.0	1117.0	1221.0	866.0	0.0	9493.0
FIXED LOGISTIC										
INIT SPARES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OTHER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INITIAL TRAINING	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3760.0
MISC. INVEST.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14784.0
TOTAL INVESTMENT	0.0	0.0	1720.1	9048.3	12370.5	17172.6	19039.1	13934.3	-37704.2	125543.4
OPERATING COSTS										
ANNUAL MAINT.										
SOFTWARE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SPARES/DEPOT	470.0	470.0	482.0	546.0	620.0	620.0	620.0	620.0	0.0	8250.0
SHIP PERSONNEL										
ET BILLETS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RM BILLETS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SHIP PERS COSTS										
ET	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL TRNG.	1255.8	1255.8	1287.6	1457.2	1653.3	1653.3	1653.3	1653.3	0.0	22047.9
SUPPLIES	-688.5	-688.5	-704.7	-795.3	-902.9	-902.9	-902.9	-902.9	0.0	-12065.1
MISC. OPER.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL OPERATIONS	1037.3	1037.3	1064.9	1207.9	1370.4	1370.4	1370.4	1370.4	0.0	18232.8
TOTAL ANNUAL COST	1037.3	1037.3	2785.0	10256.2	13740.9	18543.0	20409.5	15304.7	-37704.2	143775.9

TOTAL DISCOUNTED COST (TO 1978): $ 94597.3

Table VII-17

Total Discounted Avoidable Cost By Aggregate Ship Class
The V2 Only Scenario
(All Costs in Thousands of FY 1978 Dollars)

Aggregate Ship Class	Total Discounted Avoidable Cost
CV, CVN	2.2
Large Cruisers	0.5
Small Cruisers	7.1
DD, DDG	27.7
FF, FFG	16.8
LCC, LHA, LPD, LPH	16.6
Small Amphibious Warships	11.4
AD	1.4
AFS	1.5
AS	2.4
Other Auxiliaries	6.9
Residual*	0.1
Total	94.6

* Includes RDT&E, Software Maintenance and Annual Instructor Training.

Note: Total may not add due to rounding.

Table VII-18

NAVMACS COST-EFFECTIVENESS ANALYSIS
SCENARIO: V1, V2, & V3 ONLY

(ALL COSTS IN THOUS. FY78$)

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
RDT&E COSTS										
SOFTWARE DEVEL.	1000.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INSTR. TRNG.	900.0	0.0	600.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TEST & EVAL.	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL RDT&E	1900.0	0.0	600.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0
INVESTMENT COSTS										
EQUIPMENT	7164.0	3780.0	2784.0	4632.0	6770.0	3900.0	4996.0	0.0	0.0	0.0
INSTALLATION										
LABOR	5526.5	2479.3	2215.6	3246.2	5735.1	3899.2	3886.2	0.0	0.0	0.0
MATERIAL	772.0	406.0	306.0	558.0	1262.0	802.0	977.0	0.0	0.0	0.0
FIXED LOGISTIC										
INIT SPARES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OTHER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INITIAL TRAINING	627.0	337.0	256.0	373.0	594.5	347.5	461.0	0.0	0.0	0.0
MISC. INVEST.	0.0	4224.0	3168.0	6336.0	1056.0	0.0	0.0	0.0	0.0	0.0
TOTAL INVESTMENT	14089.5	11226.3	8729.6	15145.2	15417.5	8948.6	10320.2	0.0	0.0	0.0
OPERATING COSTS										
ANNUAL MAINT.										
SOFTWARE	0.0	0.0	0.0	0.0	0.0	0.0	300.0	300.0	300.0	300.0
SPARES/DEPOT	106.5	158.0	190.0	283.5	175.0	82.5	-38.0	-38.0	-38.0	-38.0
SHIP PERSONNEL										
ET BILLETS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RM BILLETS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SHIP PERS COSTS										
ET	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL TRNG.	218.2	329.9	414.7	538.6	738.3	855.3	1010.2	1010.2	1010.2	1010.2
SUPPLIES	-113.8	-174.4	-221.2	-287.3	-451.9	-556.0	-688.5	-688.5	-688.5	-688.5
MISC. OPER.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL OPERATIONS	210.9	313.5	383.5	534.8	461.4	381.8	583.7	583.7	583.7	583.7
TOTAL ANNUAL COST	16200.4	11539.8	9713.1	15780.0	15878.9	9330.4	10903.9	583.7	583.7	583.7

Table VII-18 (Continued)

NAVMACS COST-EFFECTIVENESS ANALYSIS
SCENARIO: V1, V2, & V3 ONLY

(ALL COSTS IN THOUS. FY78$)

	1988	1989	1990	1991	1992	1993	1994	1995	1996	TOTAL
RDT&E COSTS										
SOFTWARE DEVEL.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1000.0
INSTR. TRNG.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1500.0
TEST & EVAL.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
TOTAL RDT&E	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2600.0
INVESTMENT COSTS										
EQUIPMENT	0.0	0.0	696.0	4872.0	5568.0	6990.0	3780.0	2784.0	-25257.8	33459.2
INSTALLATION										
LABOR	0.0	0.0	354.4	2432.3	4655.3	5419.4	2479.3	2215.6	0.0	44544.4
MATERIAL	0.0	0.0	69.0	534.0	624.0	757.0	406.0	306.0	0.0	7779.0
FIXED LOGISTIC										
INIT SPARES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OTHER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INITIAL TRAINING	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2996.0
MISC. INVEST.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14784.0
TOTAL INVESTMENT	0.0	0.0	1119.4	7838.3	10847.3	13166.4	6665.3	5305.6	-25257.8	103561.4
OPERATING COSTS										
ANNUAL MAINT.										
SOFTWARE	300.0	300.0	300.0	300.0	300.0	300.0	300.0	300.0	0.0	3600.0
SPARES/DEPOT	-38.0	-38.0	-26.0	38.0	112.0	112.0	112.0	112.0	0.0	1227.5
SHIP PERSONNEL										
ET BILLETS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RM BILLETS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SHIP PERS COSTS										
ET	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL TRNG.	1010.2	1010.2	1042.0	1211.6	1407.7	1407.7	1407.7	1407.7	0.0	17040.6
SUPPLIES	-688.5	-688.5	-704.7	-795.3	-902.9	-902.9	-902.9	-902.9	0.0	-11047.2
MISC. OPER.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL OPERATIONS	583.7	583.7	611.3	754.3	916.8	916.8	916.8	916.8	0.0	10820.9
TOTAL ANNUAL COST	583.7	583.7	1730.7	8592.6	11764.1	14083.2	7582.1	6222.4	-25257.8	116982.1

TOTAL DISCOUNTED COST (TO 1978) : $ 78465.0

and depot maintenance, at least until some of the current systems are replaced. [1/]

In Table VII-19 the total discounted costs by aggregate ship class are shown. Because only the V1 through V3 configurations are installed, these are lower, in every class, than under the Full Capability scenario.

5. The Postponement Scenario

The Postponement scenario is basically the same as the V1-V3 scenario with the difference being the scheduling of the installations. Basically, installations on the smaller ship classes, for which a V1 configuration would be used, are postponed until the V1 configuration becomes available in FY 1982. In Table VII-20, the results of the cost analysis for the Postponement scenario are provided. The total discounted cost of this scenario is $64 million. The lower cost, when compared to the V1-V3 scenario arises because, first, small ships are not given the larger V2 configuration during the period FY 1978 and FY 1981 and, second, postponement of the equipment costs until later years results in a lower discounted cost. The average discounted cost per ship in this scenario is about $210,000.

1/ Recall that the operating costs from currently installed systems are assumed not to be avoidable until after the end of their economic life when replacement systems are installed.

Table VII-19

Total Discounted Avoidable Cost By Aggregate Ship Class
The V1-V3 Scenario
(All Costs in Thousands of FY 1978 Dollars)

Aggregate Ship Class	Total Discounted Avoidable Cost
CV, CVN	4.7
Large Cruisers	0.9
Small Cruisers	7.0
DD, DDG	19.9
FF, FFG	13.2
LCC, LHA, LPD, LPH	16.9
Small Amphibious Warships	4.5
AD	1.1
AFS	1.3
AS	2.2
Other Auxiliaries	2.9
Residual*	3.9
Total	78.4

* Includes RDT&E, Software Maintenance and Annual Instructor Training.

Note: Total may not add due to rounding.

Table VII-20

NAVMACS COST-EFFECTIVENESS ANALYSIS
SCENARIO: POSTPONE INSTALLATIONS

(ALL COSTS IN THOUS. FY78$)

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
RDT&E COSTS										
SOFTWARE DEVEL.	1000.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INSTR. TRNG.	900.0	0.0	600.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TEST & EVAL.	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL RDT&E	1900.0	0.0	600.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0
INVESTMENT COSTS										
EQUIPMENT	2640.0	1866.0	1044.0	2718.0	8370.0	5800.0	7296.0	0.0	0.0	0.0
INSTALLATION										
LABOR	1665.9	648.9	738.9	1605.2	8111.4	6714.0	7300.8	0.0	0.0	0.0
MATERIAL	274.0	153.0	108.0	351.0	1568.0	1171.0	1418.0	0.0	0.0	0.0
FIXED LOGISTIC										
INIT SPARES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OTHER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INITIAL TRAINING	211.0	161.0	96.0	197.0	746.5	528.0	679.5	0.0	0.0	0.0
MISC. INVEST.	0.0	4224.0	3168.0	6336.0	1056.0	0.0	0.0	0.0	0.0	0.0
TOTAL INVESTMENT	4790.9	7292.9	5154.9	11210.2	19851.9	14213.0	16694.3	0.0	0.0	0.0
OPERATING COSTS										
ANNUAL MAINT.										
SOFTWARE	0.0	0.0	0.0	0.0	0.0	0.0	300.0	300.0	300.0	300.0
SPARES/DEPOT	54.5	84.0	96.0	167.5	3.0	-156.0	-357.0	-357.0	-357.0	-357.0
SHIP PERSONNEL										
ET BILLETS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RM BILLETS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SHIP PERS COSTS										
ET	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL TRNG.	80.4	133.8	165.6	231.2	482.1	659.9	888.4	888.4	888.4	888.4
SUPPLIES	-35.8	-63.4	-80.2	-113.3	-325.9	-487.0	-688.5	-688.5	-688.5	-688.5
MISC. OPER.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL OPERATIONS	99.1	154.4	181.4	285.4	159.2	16.9	142.9	142.9	142.9	142.9
TOTAL ANNUAL COST	6790.0	7447.3	5936.3	11595.6	20011.1	14229.9	16837.2	142.9	142.9	142.9

Table VII-20 (Continued)

NAVMACS COST-EFFECTIVENESS ANALYSIS
SCENARIO: POSTPONE INSTALLATIONS

(ALL COSTS IN THOUS. FY78$)

	1988	1989	1990	1991	1992	1993	1994	1995	1996	TOTAL
RDT&E COSTS										
SOFTWARE DEVEL.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1000.0
INSTS. TRNG.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1500.0
TEST & EVAL.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
TOTAL RDT&E	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2600.0
INVESTMENT COSTS										
EQUIPMENT	0.0	0.0	696.0	4872.0	5568.0	2466.0	1866.0	1044.0	-19109.1	27136.9
INSTALLATION										
LABOR	0.0	0.0	354.4	2432.3	4655.3	1558.8	848.9	738.9	0.0	37576.6
MATERIAL	0.0	0.0	69.0	534.0	624.0	259.0	193.0	108.0	0.0	6670.0
FIXED LOGISTIC										
INIT SPARES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OTHER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INITIAL TRAINING	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2619.0
MISC. INVEST.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14784.0
TOTAL INVESTMENT	0.0	0.0	1119.4	7838.3	10847.3	4283.8	2907.9	1890.9	-19109.1	88986.3
OPERATING COSTS										
ANNUAL MAINT.										
SOFTWARE	300.0	300.0	300.0	300.0	300.0	300.0	300.0	300.0	0.0	3600.0
SPARES/DEPOT	-357.0	-357.0	-345.0	-281.0	-207.0	-207.0	-207.0	-207.0	0.0	-3347.0
SHIP PERSONNEL										
ET BILLETS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RM BILLETS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SHIP PERS COSTS										
ET	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL TRNG.	888.4	888.4	920.2	1089.8	1285.9	1285.9	1285.9	1285.9	0.0	14237.0
SUPPLIES	-688.5	-688.5	-704.7	-795.3	-902.9	-902.9	-902.9	-902.9	0.0	-10348.2
MISC. OPER.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL OPERATIONS	142.9	142.9	170.5	313.5	476.0	476.0	476.0	476.0	0.0	4141.8
TOTAL ANNUAL COST	142.9	142.9	1269.9	8151.8	11323.3	4759.8	3383.9	2366.9	-19109.1	95727.9

TOTAL DISCOUNTED COST (TO 1978): $ 64153.0

In Table VII-21 the total discounted costs by aggregate ship class are shown. The impact of postponing the installation of NAVMACS equipment on the smaller ship classes is evident in the relatively low costs associated with destroyers, frigates, small amphibious warfare ships, and small auxiliaries.

6. <u>The Large Ships Only Scenario</u>

The sixth, and final, scenario which we have analyzed assumes that the V2 and V3 configurations are available but that only the larger aggregate ship classes will have any type of NAVMACS equipment installed. As we noted above in Section A, 131 ships eventually have NAVMACS capability under this scenario.

In Table VII-22, the results of the cost analysis for this scenario are presented. As shown there, total discounted costs are $37 million. The average discounted cost per ship in this scenario is about $300,000. While this average cost is higher than in the previous two scenarios, it is due to the fact that only the larger ships are receiving NAVMACS equipment. If we considered the average cost for all 310 ships, the average cost would be about $120,000.

In Table VII-23, the total discounted costs by aggregate ship class are presented. Except for the replacement of currently installed systems, the smaller classes will have zero cost under this scenario. For the large ship classes, the results would be the same as for the V1-V3 scenario except that in this scenario the CVT does not receive any NAVMACS capability.

Table VII-21

Total Discounted Avoidable Cost By Aggregate Ship Class

The Postponement Scenario

(All Costs in Thousands of FY 1978 Dollars)

Aggregate Ship Class	Total Discounted Avoidable Cost
CV, CVN	4.7
Large Cruisers	0.9
Small Cruisers	7.0
DD, DDG	11.6
FF, FFG	7.3
LCC, LHA, LPD, LPH	16.9
Small Amphibious Warships	4.5
AD	1.1
AFS	1.3
AS	2.2
Other Auxiliaries	2.9
Residual *	3.9
Total	64.2

* Includes RDT&E, Software Maintenance and Annual Instructor Training.

Note: Total may not add due to rounding.

Table VII-22

NAVMACS COST-EFFECTIVENESS ANALYSIS
SCENARIO: LARGE SHIPS ONLY

(ALL COSTS IN THOUS. FY78$)

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
RDT&E COSTS										
SOFTWARE LEVEL.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INSTR. ENG.	900.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TEST & EVAL.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL RDT&E	900.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INVESTMENT COSTS										
EQUIPMENT	2640.0	1566.0	1044.0	2718.0	2070.0	600.0	996.0	0.0	0.0	0.0
INSTALLATION										
LABOR	1665.5	747.2	738.9	1608.2	998.1	327.4	357.4	0.0	0.0	0.0
MATERIAL	274.0	164.0	108.0	351.0	275.0	76.0	115.0	0.0	0.0	0.0
FIXED LOGISTIC										
INIT SPARES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OTHER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INITIAL TRAINING	211.0	144.0	56.0	157.0	148.0	34.0	81.0	0.0	0.0	0.0
MISC. INVEST.	0.0	4224.0	3168.0	6336.0	1056.0	0.0	0.0	0.0	0.0	0.0
TOTAL INVESTMENT	4790.5	6845.2	5154.9	11210.2	4537.1	1037.4	1549.4	0.0	0.0	0.0
OPERATING COSTS										
ANNUAL MAINT.										
SOFTWARE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SPARES/DEPOT	54.5	72.5	84.5	156.0	212.0	235.0	254.5	254.5	254.5	254.5
SHIP PERSONNEL										
ET BILLETS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RM BILLETS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SHIP PERS COSTS										
ET	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL TRNG.	80.4	128.1	159.9	225.5	274.8	286.2	313.1	313.1	313.1	313.1
SUPPLIES	-35.8	-60.8	-77.6	-110.7	-135.6	-141.2	-155.1	-155.1	-155.1	-155.1
MISC. OPER.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL OPERATIONS	99.1	139.8	166.8	270.8	351.2	380.0	412.5	412.5	412.5	412.5
TOTAL ANNUAL COST	5790.0	6985.0	5321.7	11481.0	4888.3	1417.4	1961.9	412.5	412.5	412.5

Table VII-22 (Continued)

NAVMACS COST-EFFECTIVENESS ANALYSIS
SCENARIO: LARGE SHIPS ONLY

(ALL COSTS IN THOUS. FY78$)

	1988	1989	1990	1991	1992	1993	1994	1995	1996	TOTAL
RDT&E COSTS										
SOFTWARE DEVEL.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INSTR. TRNG.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	900.0
TEST & EVAL.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL RDT&E	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	900.0
INVESTMENT COSTS										
EQUIPMENT	0.0	0.0	696.0	4672.0	5568.0	2466.0	1566.0	1044.0	-14829.6	13016.4
INSTALLATION										
LABOR	0.0	0.0	354.4	2432.3	4655.3	1558.8	747.2	738.9	0.0	16920.0
MATERIAL	0.0	0.0	69.0	534.0	624.0	259.0	164.0	108.0	0.0	3121.0
FIXED LOGISTIC										
INIT SPARES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
OTHER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INITIAL TRAINING	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	911.0
MISC. INVEST.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14784.0
TOTAL INVESTMENT	0.0	0.0	1119.4	7838.3	10847.3	4283.8	2477.2	1890.9	-14829.6	48752.3
OPERATING COSTS										
ANNUAL MAINT.										
SOFTWARE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SPARES/DEPOT	254.5	254.5	266.5	330.5	404.5	404.5	404.5	404.5	0.0	4556.5
SHIP PERSONNEL										
ET BILLETS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RM BILLETS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SHIP PERS COSTS										
ET	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ANNUAL TRNG.	313.1	313.1	344.9	514.5	710.6	710.6	710.6	710.6	0.0	6735.3
SUPPLIES	-155.1	-155.1	-171.3	-261.9	-369.5	-369.5	-369.5	-369.5	0.0	-3403.5
MISC. OPER.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL OPERATIONS	412.5	412.5	440.1	583.1	745.6	745.6	745.6	745.6	0.0	7888.3
TOTAL ANNUAL COST	412.5	412.5	1559.5	8421.4	11592.9	5029.4	3222.8	2636.5	-14829.6	57540.5

TOTAL DISCOUNTED COST (TO 1978): $ 37121.7

Table VII-23

Total Discounted Avoidable Cost By Aggregate Ship Class
The Large Ships Only Scenario
(All Costs in Thousands of FY 1978 Dollars)

Aggregate Ship Class	Total Discounted Avoidable Cost
CV, CVN	4.1
Large Cruisers	0.9
Small Cruisers	7.0
DD, DDG	0.8
FF, FFG	1.3
LCC, LHA, LPD, LPH	16.9
Small Amphibious Warships	0.2
AD	1.1
AFS	1.3
AS	2.2
Other Auxiliaries	0.3
Residual *	1.1
Total	37.1

* Includes RDT&E, Software Maintenance and Annual Instructor Training.

Note: Total may not add due to rounding.

C. Sensitivity Analysis

The six scenarios that have been analyzed in the previous section provide a wide range of alternative schedules, configurations, and configuration-aggregate ship class pairings, and, therefore, enable the sensitivity of cost to such decisions to be readily quantified. In this section, the impact on cost of two specific factors that have been used in the analyses is analyzed. First, we examine the sensitivity of the results to the assumption of a 15 year economic life. Second, we consider the effect of a more expensive V1 configuration.

1. Sensitivity to Economic Life

It is well known that (properly maintained) electronics equipment has a very long, if not infinite, technical life. Other factors, for example, technical progress, can make such equipment obsolete, resulting in a finite economic life. In our cost analyses, we have used a 15 year economic life. Suppose, instead, that the economic life is 21 years, i.e., it covers the period FY 1975-FY 1995. Thus, installed NAVMACS equipment would not be replaced during the period considered in our study. [1/] This will clearly lower the cost of all scenarios since there will be less equipment cost in all cases.

1/ This particular sensitivity (and the related one below) are also appropriate if it is believed that NAVMACS equipment will only be replaced when a newer system is installed.

In Table VII-24, the total discounted cost of each scenario is shown for both economic lives. Also shown in Table VII-24 are both the absolute and percentage differences that result when a 21 year economic life is assumed in place of a 15 year economic life. As we would expect, the absolute differences are greatest for those scenarios having the largest total discounted costs. This is due simply to the fact that the higher cost scenarios have the largest equipment cost. The more interesting fact is that the greatest decreases in cost due to the 21-year life occurs in the AMT and V2 Only scenarios, as a result of the low remaining value of the equipment in 1995. Finally, we note that the relative rankings of the alternatives are not affected as a result of this change.

A related sensitivity analysis considers the impact of not considering the value of the remaining economic life. In conjunction with the 21 year economic life assumption, this amounts to assuming that all equipment lasts through the time horizon and, in the following year, is valueless. In Table VII-25, the total costs for each of the scenarios is shown when these two assumptions are made. In Table VII-25, we see that the ranking of the scenarios is not affected. The costs of the AMT scenario and the V2 Only scenario are reduced the most since they incur the equipment costs earlier than the other scenarios and, this equipment, therefore, has less economic life remaining.

Table VII-24

Sensitivity of the Results to Economic Life

(All Costs in Millions of FY 1978 Dollars)

Scenario	Total Discounted Avoidable Cost 15 Yr. Life	Total Discounted Avoidable Cost 21 Yr. Life	Absolute Difference	Percentage Difference
AMT	$111	$ 96	$15	-13.5
Full Capability	148	135	13	- 8.8
V2 Only	95	80	15	-15.8
V1-V3	78	68	10	-12.8
Postpone Installations	64	57	7	-10.9
Large Ships Only	37	31	6	-16.2

Table VII-25

Total Discounted Avoidable Costs Assuming No Replacement Costs and No Salvage Value

(All Costs in Millions of FY 1978 Dollars)

Scenario	Total Discounted Avoidable Cost
AMT	$100
Full Capability	144
V2 Only	84
V1-V3	71
Postpone Installations	60
Large Ships Only	32

2. <u>Sensitivity to V1 Configuration Equipment Cost</u>

In Chapter VI, we mentioned that the equipment cost for the V1 configuration was subject to greater uncertainty than the equipment cost of other configurations. Therefore, the costs of the scenarios incorporating the V1 configuration were recalculated using an assumed equipment cost of $150,000 to determine what impact this would have on the ranking of the scenarios. In making this change in equipment cost, we have not altered any other costs (e.g., spares) as a result. The results are shown in Table VII-26.

Table VII-26

Sensitivity to V1 Configuration Equipment Cost
(All Costs in Millions of FY 1978 Dollars)

	Total Discounted Avoidable Cost	
	$100,000 V1 Equipment Cost	$150,000 V1 Equipment Cost
AMT	$111	$111
Full Capability	148	150
V2 Only	95	95
V1-V3	78	81
Postpone Installations	64	70
Large Ships Only	37	37

Naturally, the costs do not change for the AMT, V2 Only, or Large Ships Only scenarios. The results in Table VII-26 also show that the costs of the other scenarios are affected in only a minor way by this assumption.

D. Summary

The results of the cost analysis are readily summarized in Table VII-27. There, the total discounted costs of each scenario are presented with two qualitative measures of the NAVMACS capability associated with the scenarios: the total number of ships eventually having NAVMACS equipment and the configurations installed. These are included to provide a rough measure of the overall level of automated communications capability in the individual scenarios.

Table VII-27

Total Discounted (to FY 1978) Avoidable Costs

(Millions of FY 1978 Dollars)

Scenario	Configurations Installed	No. of Ships with NAVMACS	Cost
AMT	V2, V3	310	$111
Full Capability	V1-V5	310	148
V2 Only	V2	310	95
V1-V3	V1-V3	310	78
Postpone	V1-V3	310	64
Large Ships Only	V2, V3	131	37

As shown in Table VII-27, total discounted costs range from $37 million to $148 million, i.e., the high-cost and low-cost scenarios vary by more than a factor of four. The ranking of scenarios offers no surprises. The scenario with the greatest automated capability (the Full Capability scenario) also has the greatest cost. The AMT scenario, which includes no V1 configuration, is the next most expensive. Comparing the AMT scenario with the V2 scenario (the most comparable in scheduling and total number of ships) indicates that the incremental (discounted) cost of installing the V3's on large ships is $16 million, for 36 V3 installations. This represents an average incremental cost for these installations of about $450,000.

The costs of V1-V3 scenario and the Postponement scenario, most comparable to the Full Capability scenario in terms of scheduling incremental costs associated with two specific decisions. Namely, the incremental cost of installing the V4 and V5 configuration is about $70 million. The incremental cost of installing V2's on smaller ship classes while awaiting the introduction of the V1 configuration is about $14 million. The first difference is clearly significant and the second represents almost 20 percent of the total cost.

Finally, the cost of the Large Ships Only scenario indicates that a savings of $27 million can be realized over the Postponement scenario by not installing any NAVMACS capability on the smaller aggregate ship classes. Compared to the other scenarios the savings are $41 million over the V1-V3 scenario, $58 million over the V2 Only scenario, $74 million over the AMT scenario and $111 million over the Full Capability scenario.

A second comparison among the scenarios can be made by considering the relative avoidable costs by major cost category (RDT&E, investment, and operating). In Table VII-28, the total discounted avoidable costs for these categories is shown for all scenarios. As is evident, avoidable investment plays a dominant role in all scenarios. Even in the Full Capability scenario it represents 77 percent of the total discounted avoidable costs. Notice that the ranking of the six scenarios is unchanged if avoidable investment costs only are used. Since the primary investment cost factors (e.g., equipment and installation) are relatively well agreed upon and/or substantiable, the overall ranking will not be sensitive to changes in most of the assumptions we have had to make about other cost factors.

Table VII-28

Total Discounted (to FY 1978) Avoidable Cost by Category

(All Costs in Millions of FY 1978 Dollars)

Scenario	RDT&E Costs	Investment Costs	Operating Cost	Total Cost
AMT	0.9	99.7	10.3	110.8
Full Capability	6.6	114.4	27.4	148.4
V2 Only	0.0	86.6	8.0	94.6
V1-V3	2.5	71.4	4.6	78.5
Postpone Installations	2.5	60.0	1.7	64.2
Large Ships Only	0.9	33.1	3.2	37.1

Note: Totals may not add due to rounding.

Still a third interesting comparison is among scenarios for the costs by aggregate ship class. Such a comparison provides information on the costs to equip specific classes and allows an assessment of these costs relative to the communications requirements of the specific classes to be made.

In Table VII-29, a breakdown of total discounted cost by aggregate ship class and scenario is provided. The classes are arrayed down the left hand column. The row labeled "Residual" consists of those costs (i.e., RDT&E and software maintenance) that are not assignable to a specific aggregate ship class. The effect of installing the V4 and V5 systems is dramatic as shown by the effect on carriers and large amphibious warships in the Full Capacity scenario. The savings that can be achieved with the V1 configuration are evident from the difference between the AMT or V2 scenarios and the V1-V3 scenarios for the smaller ship classes. For example, costs for equiping the smaller auxiliaries with V2 configurations in the AMT scenario are almost 2-1/2 times greater than the costs of using a V1 configuration as in the V1-V3 scenario.

Finally, the effect of not equiping the smaller ships with any NAVMACS capability is evident from comparing the costs of the smaller amphibious warfare ships under the Large Ships Only scenario with the costs under the V1-V3 or Postponement scenarios. 1/

1/ The reason there are any costs for the small ship classes under the Large Ships Only scenario is that ships that currently have NAVMACS equipment retain it. This equipment is, therefore, replaced at the end of its economic life.

Table VII-29

Total Discounted (to FY 1978) Avoidable Costs by Aggregate Ship Class

(Millions of FY 1978 Dollars)

Aggregate Ship Class	Scenario					
	AMT	Full Capability	V2 Only	V1-V3	Postponement	Large Ships Only
CV, CVN	3.1	13.0	2.2	4.7	4.7	4.1
Large CG	0.5	2.6	0.5	0.9	0.9	0.9
Small CG	7.1	13.1	7.1	7.0	7.0	7.0
DD, DDG	27.1	28.4	27.7	19.9	11.6	0.8
FF, FFG	16.8	13.7	16.8	13.2	7.3	1.3
LCC, LHA, LPD, LPH	28.7	48.4	16.6	16.9	16.9	16.9
Small Amphibious Warfare	12.0	4.5	11.4	4.5	4.5	0.2
AD	1.4	2.4	1.4	1.1	1.1	1.1
AFS	3.3	4.0	1.5	1.3	1.3	1.3
AS	2.4	4.0	2.4	2.2	2.2	2.2
Other Auxiliary	6.9	2.9	6.9	2.9	2.9	0.3
Residual*	1.0	11.3	0.1	3.9	3.9	1.1
Total	110.8	148.3	94.6	78.4	64.2	37.1

* RDT&E, Software Maintenance, and Annual Instructor Training.

Note: Numbers may not add due to rounding.